DEPARTMENT OF THE INTERIOR
FRANKLIN K. LANE, Secretary

UNITED STATES GEOLOGICAL SURVEY
GEORGE OTIS SMITH, Director

PROFESSIONAL PAPER 106

THE QUATERNARY GEOLOGY OF SOUTHEASTERN WISCONSIN

WITH A CHAPTER ON THE OLDER ROCK FORMATIONS

BY

WILLIAM C. ALDEN

T. C. CHAMBERLIN, GEOLOGIST IN CHARGE

WASHINGTON
GOVERNMENT PRINTING OFFICE
1918

DEPARTMENT OF THE INTERIOR
FRANKLIN K. LANE, Secretary

UNITED STATES GEOLOGICAL SURVEY
GEORGE OTIS SMITH, Director

Professional Paper 106

THE

QUATERNARY GEOLOGY OF SOUTHEASTERN WISCONSIN

WITH A CHAPTER ON THE OLDER ROCK FORMATIONS

BY

WILLIAM C. ALDEN

T. C. CHAMBERLIN, GEOLOGIST IN CHARGE

WASHINGTON
GOVERNMENT PRINTING OFFICE
1918

CONTENTS.

ILLUSTRATIONS.

PREFACE.

By T. C. Chamberlin.

The invasion of eastern Wisconsin by the late Pleistocene ice gave rise to deposits bearing declared topographic forms and thus left a record of striking individuality. A large ice lobe of the continental glacier pushed forward through the Green Bay valley in a deployment distinctly its own, and yet it worked snugly by the side of a still greater ice lobe that crept down the valley of Lake Michigan. Each lobe did its own work in its own way and left an individual record that is rich in testimony to its own history. Without seriously trammeling their independence the two ice lobes crowded against each other and pushed the terminal moraines that gathered on their adjacent sides into one rough, bunchy, gigantic ridge. This joint interlobate moraine is the master feature of the region—a feature that easily holds the primacy in its class. It is not only an object of scientific interest but a feature of popular note. It lends picturesqueness to a region that is famous for its beauty. It commanded attention from the time of the earliest exploration of the region. Its gigantic hummocks and hollows caught the imagination of the pioneer and called up the image of the great caldrons then in use for boiling down ash lye into potash cakes. Some of these kettles seemed to be set in place, and as many or more were turned upside down. Hence arose the homely but suggestive name Potash Kettle Range.

How the range came to have these singular features puzzled not only the pioneer settler but the pioneer geologist, and it became the subject of speculation and of occasional papers. The range and its associated phenomena, however, escaped serious study until about 40 years ago, when these and other glacial features of eastern Wisconsin were mapped and interpreted by the Wisconsin State Geological Survey. The interpretations then put upon the Kettle moraine have played some part in shaping later studies of like nature in other areas of the great glacial field and at length came to be in some sense paternal to the studies herein set forth.

It may serve to show how rapidly methods of deliberate inquiry are following the more hasty methods of the pioneer surveys to note that the survey in the seventies swept over the Pleistocene formations and those that underlie them at the rate of about 4,000 square miles a year, and thus perforce had something of the nature of a bird's-eye view. If the larger features then stood out in greater relative prominence it was the natural result of the surveyor's greater freedom from embarrassing details.

The present paper is a work of another order. It is a first serious study after a first serious reconnaissance. The two happen to fall into as gratifying accord as is wholesome to the progress of inquiry. The chief divergence is in the interpretation of the pebble-bearing red clay of the Lake Michigan border and the Lake Winnebago basin. The studies in this paper emphasize, as did the earlier studies, the less bowldery and less local nature of the material of this formation compared with the ground moraine below and about it. This paper also sets forth the intimate association of the pebbly clays with laminated pebbleless clays and with sheets of sand and gravel, the obvious products of aqueous action. It also emphasizes the singular redness of this formation and its marked contrast to the blue-gray till over which it lies and by which it is surrounded. The later studies ascribe the requisite coloring matter to the same source as did the earlier. In these essential features the earlier and later reports are in close accord. But the present paper differs from the Wisconsin report in assigning the origin of the pebbly-clay member of the series to the direct action of the ancient glacier, in distinction from the glacio-natant and aqueous action assigned by the earlier interpretation. For this difference of view the author of this paper marshals cogent reasons, which will no doubt carry conviction to those who are expert in this class of formations, and he is to be congratulated on this advance in interpretation. Some ground is left for surprise that the later glacier formed a product so notably different from that of the earlier glaciers in the size and source of the erratics and in that the high-red coloration was so markedly absent from the earlier till sheets and became so pronounced and characteristic of the later till sheet; but perhaps these features were incidental to the development of a bordering lake, which could be formed only after a certain extent of glacial withdrawal had taken place, and which only at this stage could reach to the region of red rocks in the Superior basin and thence derive the requisite pigment. It may be that during this marked glacial retreat red-clay sediments carried southward along the bordering lake so mantled the abandoned ground that the readvancing ice crept more smoothly over the mantled bottom and took up less local material and fewer bowlders, gathering instead the red-clay sediments and forming from them a clayey, slightly stony red till that was thus in some sense a secondary lacustrine deposit.

The newer interpretation makes less demand on theories of changes of elevation, and thus withdraws support from the old familiar idea of northern elevation and depression as potent causes of glaciation and deglaciation. This inherited view found expression in the older interpretation of these stony red clays, and its elimination is a welcome contribution to the conception of a more stable earth, which is gradually replacing the earlier tenet of a flexible crust freely oscillating under the stress of scarcely assignable agencies.

The master feature of the glacial formations of eastern Wisconsin is the interlobate moraine, a name for a type first recognized in the study of the Potash Kettle Range. The type has not always been keenly discriminated from medial moraines, with which it has little more to do dynamically than have other terminal moraines. The interlobate moraine is a special development of terminal ridging—a duplicate ridging where the borders of two glaciers or two glacial lobes of a continental glacier push their two terminal moraines into one and pour their common drainage into the trough between them and flood their joint morainic product. Where the lobes were large and their line of contact was long, it is not strange that flood work and ice burial should have reached unusual magnitudes and that the resulting hummocks and hollows and wash products should have become impressive. Because the Green Bay and Lake Michigan ice lobes kept so close a balance between independence and coalescence they gave rise to an unusual interlobate product, and thus the Kettle moraine of eastern Wisconsin came to hold its foremost place.

There are grades and degrees of interlobateness and corresponding degrees of interlobate moraines. Those at the minor end of the series are mere spear-pointed bunchings along the courses of terminal moraines where they enter angles between two ice lobes only partly differentiated. Thence they range into reentrant spurs of greater and greater extent, and at length into the major type formed where two long ice lobes, centered in independent troughs, mount by lateral growth the intervening upland and crowd against each other. An approach to this condition, which yet stopped short of it, is seen in the great moraines that lie on opposite slopes of the Coteau des Prairies in Minnesota and South Dakota, the one marking the right border of the great ice lobe that occupied the Minnesota Valley and pushed down to central Iowa, the other marking the left border of the similar great ice lobe that pushed down the James River valley. Had these lobes grown a little more and advanced laterally a few miles farther they must have given rise to a joint interlobate moraine that would have robbed the Kettle moraine of its honors.

The method of formation of such a moraine is not quite the same as that of a simple reentrant spur, though the two no doubt grade into each other. On the Coteau des Prairies the deployment of the two ice lobes was quite independent, and their striative and drumloidal characters are consistent with this independence. If the lobes involved are but minor differentiations of a common broad ice field, the main basal work recorded in gravings and linear heapings conforms chiefly to the common movement and is not seriously affected by the shallow marginal lobation. A chain of interlobate moraines may indeed be formed one after another by successive junctions of moraines during a retreat marked by a series of halts or small advances, and such a chain of interlobate moraines may closely simulate the features of a great interlobate moraine formed by two extended ice lobes pushing their side moraines together. Whether the one or the other of these two types is most nearly approached in eastern Wisconsin perhaps needs further thought, data for which are furnished by the drumlins, striæ, and other movement features described or mapped in this paper. These seem to imply that the main basal work of the Green Bay and Lake Michigan ice lobes was that of independent well-individualized bodies, and that the work systems of both were essentially consistent throughout.

In analyzing and interpreting the latest-formed features of the interlobate moraine and connecting these features with the slender, patchy, scarcely traceable later moraines that loop across the abandoned lobate areas, the author of this paper has perhaps given encouragement to the thought that the Kettle moraine is but a chain of successive reentrant moraines; but the drumlin systems of the two lobate areas do not respond well to this interpretation. No doubt there were such successive reentrants, and their delineation and interpretation are important; but as such phenomena would inevitably attend both a chain of reentrants and a single interlobate moraine the fundamental problem remains for consideration. It is of some moment to discern an underlying uniting moraine of the major type if it exists. The development of the drumlin systems and the profounder striative systems warrants the view that this interlobate moraine belongs to the major class.

Many other features of the paper invite comment, but this word of introduction must not lapse into a review. The writer of this prefatory note can ask for the author of the paper no greater measure of considerateness and equipoise of judgment than the author has himself shown in the treatment of his subject and of his predecessors.

THE QUATERNARY GEOLOGY OF SOUTHEASTERN WISCONSIN, WITH A CHAPTER ON THE OLDER ROCK FORMATIONS.

By William C. Alden.

Chapter I.—INTRODUCTION.

ADVANCE AND RETREAT OF THE ICE.

The Quaternary deposits of eastern Wisconsin are particularly interesting to students of this latest of the geologic ages largely because the Green Bay Glacier, a well-defined unit among the glacial lobes which characterized the borders of the great North American ice sheets, traversed the eastern part of the State under topographic conditions which, while sufficiently marked to show the effects of topographic control on glacial flow, were yet of such comparatively small relief that the glacier deployed freely and with only moderate asymmetry. There were thus afforded conditions favorable for the development of nearly all phases of glacial, glacio-fluvial, glacio-lacustrine, and aero-glacial deposits, such as are typical of continental glaciation as contrasted with the phenomena of mountain glaciation. Not only this but the environs afforded a variety of periglacial conditions. Differentiated from the greater Lake Michigan Glacier on the east by entering the Green Bay-Winnebago trough, it moved in a direction somewhat west of south up this broad, open valley. It surmounted the Niagara escarpment on the east and advanced to meet the opposing front of the Lake Michigan Glacier, the laterally deploying ice flows meeting along the line of the great Kettle interlobate moraine. Crossing the low divide the glacier entered the basin of Rock River, where it spread out over the deposits of earlier glacial incursions, deploying radially to a broadly curving morainic arc of 160°. Beyond, a moderately eroded sheet of older drift mantled an earlier dissected topography, and at its south front the widely spreading tributary arms of the Rock River drainage system gathered in the glacial waters with their load of outwash sands and gravels. On the west, in Adams, Sauk, and Dane counties, this ice of the last great advance extended beyond the limits of earlier glaciation and encroached upon the greatly dissected topography of the Driftless Area. South of the Baraboo quartzite range the glacial waters escaped principally to the Mississippi by way of the Wisconsin River valley, where an interesting series of terraces are found. Straddling over the highest part of the quartzite range, the glacial margin looped sharply back in such manner that the limit of the drift, still clearly traceable, affords evidence of the abruptness and height of the marginal slope of the ice and gives some suggestion as to the thickness attained by the glacier farther back. The conjunction of the glacial front with the quartzite range completed a great dam blocking all the drainage of Baraboo River and the upper part of Wisconsin River and giving rise to a great glacial lake, which spread widely over the sandy plains of the northeastern part of the Driftless Area.

The process of freeing the region from ice by the melting of the glaciers at the close of the last glacial winter was interrupted by a declining series of readvances of the ice fronts. Similar phenomena also characterized the history of the Lake Michigan Glacier and to a certain extent that of the earlier ice sheets. The disappearance of the ice left the preglacial topography, which in places corresponded in the degree of its dissection by stream erosion with that of the Driftless Area as we see it to-day, covered with a mantle of drift varying in thickness from a few inches to 500 or 600 feet. A large part of this was concentrated in the valleys, partly filling many and totally obliterating some as features of the topography. Where drift was concentrated in marginal moraines streams were diverted from their former courses and many drainage lines were blocked, producing basins whose flooding produced both the many beautiful lakes for which the region is famous and the wet lands now occupied by the many swamps and marshes. With the amelioration of the climate and the disappearance of the ice vegetation spread over the surface of the drift, covering the barren waste of glacial débris with verdure. The birds of the air, the beasts of the field, and the fishes of the streams reoccupied the area from which they were probably very largely excluded during the glacial occupation. The addition or shifting about of wind-blown dust and sand and the alteration of the surficial parts of the drift by humic acids derived from the vegetation and by solution, leaching, and precipitation by meteoric waters and oxidation by the penetrating atmosphere developed the fertile soil.

HUMAN OCCUPATION.

Geologic investigation has not brought to light any evidence as to when the region was first occupied by primeval man. It is not known whether he followed the faunas and floras that reoccupied the area after each successive melting of the ice or whether his occupancy was confined to Recent time. The wonderful effigy mounds and the abundant implements of domestic life and of warfare and the chase which yet remain as relics of prehistoric man in this region are all found upon the surface of the drift or in situations showing artificial or recent burial. No fossil bone or artificial product has been found so buried in the drift of Wisconsin as to demonstrate beyond a reasonable doubt that man occupied this country prior to or during the great ice age. The study of these peoples is thus the province of the ethnologist and historian and not of the geologist. The coming of the white man, the cutting of the forests, the tilling of the soil on hill and plain, the development of natural and artificial routes of transportation, the discovery and utilization of the stores of mineral wealth, and the development of hydraulic power have completed the change of a region which was once an ice field as repellent and as devoid of scenic variety as the ice cap of Greenland or the environments of the pole to one of the richest and most beautiful of the inhabited parts of the continent.

PURPOSE OF THIS REPORT.

The study of these changes and the processes by which they were wrought is one of the most fascinating of the lines of scientific investigation. It is the purpose of this report to set forth the results of an investigation of these phenomena which has been carried on for the United States Geological Survey for a number of years by the writer under the direction of Dr. T. C. Chamberlin, of the University of Chicago, and it is hoped that some worthy contribution may be made to the sum of our knowledge concerning this interesting region.

ACKNOWLEDGMENTS.

It is a pleasure to acknowledge great indebtedness to the work of other investigators in this field, and particularly to Dr. Chamberlin, whose studies on the drift in this and other parts of the United States are classics in glacial geology. One working over such an area as this, which was previously studied by this master, with his writings close at hand for reference, is constantly impressed with the thoroughness and accuracy of those observations and the clear and convincing character of their description and interpretation. It is, in fact, almost discouraging at times to follow the footsteps of an investigator of such ability, where it seems as though practically everything has already been seen and explained. Changes in the trend of scientific thought and the results of investigations in other fields, however, often put matters in a different light and require changes in former interpretation, while the collecting of additional evidence, a little here and a little there, for which opportunity is offered by continued development of the country, may add to the sum of knowledge by an increment well worth the expenditure of effort, time, and money involved. Knowledge is one of the greatest of human acquisitions, and from no branch is there greater return than from knowledge of the natural conditions under which we live, the knowledge of the earth as we find it to-day, and of the processes

involved in bringing about those conditions on which so much of our happiness and welfare depend. The work of this survey has been carried on not only under the supervision of Dr. Chamberlin, but it is in very large measure practically his own work, because of his large contribution through frequent conferences, by direction, suggestions, and interpretation. The writer is, however, in the main responsible for the field observations, the details of correlation, and for this presentation.

It is also a pleasure to acknowledge the help received from a number of former students of the University of Chicago, who at different times served as assistants in the field mapping. These are J. H. Smith, Eliot Blackwelder, William Averill, Frank De Wolf, W. H. Emmons, Eli Gale, Ray Johnson, E. S. Bastin, R. T. Chamberlin, J. L. Tilton, Howard Simpson, G. F. Kay, A. D. Hole, C. G. Shatzer, R. A. Rowley, H. H. Barrows, S. L. Stoner, J. A. Smyser, A. C. Miller, W. D. Jones, and G. J. Miller. In addition to these, E. R. Scheffel, Lawrence College, Appleton, Wis., served as assistant in the summer of 1909 and F. T. Thwaites, Madison, Wis., was employed as special field assistant in the summer of 1907. Besides the assistance thus rendered by Mr. Thwaites his detailed studies in the vicinity of Madison have supplemented those of the writer in many particulars.

The writer desires to make grateful acknowledgment of the use of notes, maps, and an unpublished manuscript prepared by I. M. Buell, who spent several seasons studying the drift phenomena of a large portion of the area treated in this paper. These studies were carried on under the supervision of Dr. Chamberlin and were directed primarily to the solution of problems involved in the derivation and distribution of quartzite drift from the quartzite ledges of the Waterloo district.

Acknowledgment is also made for information and assistance furnished by Dr. E. A. Birge, Dr. William O. Hotchkiss, Dr. Samuel Weidman, and their associates of the Wisconsin Geological and Natural History Survey. The writer is also much indebted to hundreds of people scattered throughout the area under investigation for information and favors which have very materially aided in the work.

BIBLIOGRAPHY.

The following is an annotated list of publications issued from 1836 to 1916, in which are discussed, either primarily or incidentally, geologic phenomena within the part of Wisconsin treated in the present work. To nearly all of these the writer has had access, and it is a pleasure to acknowledge indebtedness thereto. The list does not include textbooks on geology and physiography, most of which contain numerous references to phenomena developed in southeastern Wisconsin. Both the list itself and part of the notes are compiled from the bibliographies and indices of North American geology prepared for the United States Geological Survey by N. H. Darton, F. B. Weeks, and J. M. Nickles.[1]

1836. Featherstonhaugh, G. W., Report of a geological reconnaissance made in 1835 from the seat of government by the way of Green Bay and the Wisconsin Territory to the Coteau du Prairie, an elevated ridge dividing the Missouri from the St. Peters River.

1840. Owen, D. D., Report of a geological exploration of part of Iowa, Wisconsin, and Illinois in 1839: Message President of United States concerning the mineral lands of the United States, 26th Cong., 1st sess., H. Ex. Doc. 239, pp. 9–115; 28th Cong., 1st sess., S. Ex. Doc. 407, pp. 15–145, 1844. Contains, with other data, notes on minerals erals and character of lands in Tps. 1–8, 9, 10, or 11, Rs. 4–8 E. of the fourth principal meridian.

1842. Hall, James, Notes on the geology of the western States: Am. Jour. Sci., 1st ser., vol. 42, pp. 51–62. Refers to relations of the formations in Wisconsin to those in New York.

1843. Hall, James, Geology of New York, pt. 4. Contains geologic map of the middle and western States, including eastern and southern Wisconsin, of the character and distribution of whose rock formations there was very meager knowledge.

1846. Owen, D. D., On the geology of the western States of North America: Geol. Soc. Quart. Jour., vol. 2, pp. 433–447. Geological map includes part of southern Wisconsin and indicates very meager knowledge of this region.

1847. Lapham, I. A., On the existence of certain lacustrine deposits in the vicinity of the Great Lakes, usually confounded with the "Drift": Am. Jour. Sci., 2d ser., vol. 3, pp. 90–94.

1851. Desor, E., On the superficial deposits of this district: Geology of the Lake Superior land district, pt. 2, chaps. 14, 15, 16, S. Ex. Doc. 4. Describes drift on upper peninsula of Michigan. Gives evidence of the southwesterly movement of the

[1] Bibliography and index of North American geology, 1732–1891 (Bull. 127), 1892–1900 (Bulls. 188, 189), 1901–1905 (Bull. 301), 1906–7 (Bull. 372), 1908 (Bull. 409), 1909 (Bull. 444), 1910 (Bull. 495), 1911 (Bull. 524) 1912 (Bull. 545), 1913 (Bull. 584), 1914 (Bull. 617), 1915 (Bull. 645).

transporting agent based on striæ and the derivation of drift. In a section by Whittlesey the origin of the ancient beaches of Lake Michigan is referred to higher lake levels since the deposition of the drift, and the higher lake levels are referred to a long succession of humid seasons over the whole area, the outlets not being regarded as sufficient for a rapidly accumulating surplus to pass off within several years.

Foster, J. W., and Whitney, J. D., Geology of the Lake Superior land district, pt. 2, The iron region together with the general geology: S. Ex. Doc. 4. Includes a section "On the geology of the southeastern portion of the State of Wisconsin, being the part not surveyed by the United States geologists, in a letter to J. W. Foster by I. A. Lapham, of Milwaukee." The sandstone exposed near Janesville is correlated with the Potsdam. [Since that time it has been found to be St. Peter.] Refers to the rock at the "granite quarries" at Portland in Dodge County as metamorphic sandstones. Refers the limestone above the sandstone at Janesville to the Lower Magnesian. [This was later found to be Trenton.] From sand and sandstone in the drift he infers the possible presence of a sandstone above the Galena. Refers to the iron ore in Dodge and Washington counties below the Niagara dolomite. Notes the thin shaly limestone near Milwaukee below the Devonian and refers it to the "Corniferous." Refers to black shale fragments in the drift as probable evidence of the presence of black shale not far to east. In a section by Charles Whittlesey reference is made to the red clay and drift in the Green Bay trough and bordering Lake Michigan. Quoting Hall he refers the origin of the basin of Lake Michigan not to faulting and displacement but to excavation of "Onondaga Salt Group" and "Upper Helderberg series" by southward-flowing waters.

Whittlesey, Charles, On the "superficial deposits" of the northwestern part of the United States: Am. Assoc. Adv. Sci. Proc., vol. 5, pp. 54–57. In this is some discussion of the red and blue drift and lake clays of eastern Wisconsin, also reference to the "Potash Kettle" country between Sheboygan and Fond du Lac.

1852. Owen, D. D., Report of a geological survey of Wisconsin, Iowa, and Minnesota, and incidentally of a portion of Nebraska, made under instructions from the United States Treasury Department. This includes, in the chapters by Col. Whittlesey, a description of the "Iron Ridge" and ore beds of Dodge County, Wis., a description of the rocks in the eastern part of the State, and a discussion of the red clay and drift bordering the shores of Lake Michigan, Lake Winnebago, and Green Bay. In the chapters by B. F. Shumard the rock formations along Wisconsin and Baraboo rivers and elsewhere are described.

1853. Barrande, J. [Silur-Fauna in Wisconsin and in New York]: Neues Jahrb., pp. 335–347.

1854. Owen, D. D., On a geological map of Wisconsin, Iowa, and Minnesota: Philadelphia Acad. Sci. Proc., vol. 6, pp. 189–191.

1855. Lapham, I. A., Geological map of Wisconsin, New York: Idem, Milwaukee, 1869.

Owen, D. D., Catalogue of geological specimens collected by D. D. Owen and deposited in the Smithsonian Inst.: Smithsonian Rept. for 1854, pp. 393–396.

Percival, J. G., Annual report on the geological survey of the State of Wisconsin. Includes some notes on the drift of the region south of Madison and west of Janesville. Refers to the Baraboo quartzite as changed "Lower" or "Potsdam" sandstone, and says that the rocks at Portland in like manner result from the "Upper" or St. Peter sandstone. Explains the Driftless Area in southwestern Wisconsin by deflection of the drift-carrying agency around the ends of Military Ridge.

1856. Percival, J. G., Jahresbericht der Geologischen Vermessung des Staates Wisconsin.

1859. McChesney, J. H., Description of new fossils from the Paleozoic rocks of the Western States: Chicago Acad. Sci. Trans., Oct. 11, 1859. Describes a few species from the Niagara dolomite of eastern Wisconsin.

1860. Whittlesey, Charles, On the drift cavities or "potash kettles" of Wisconsin: Am. Assoc. Adv. Sci. Proc., vol. 13, pp. 301–308. Describes the topography along what is now known as the Kettle interlobate moraine and suggests that the depressions are the result of the melting of buried masses of glacier ice.

Lapham, I. A., Discovery of Devonian rocks and fossils in Wisconsin: Am. Jour. Sci., 2d ser., vol. 29, p. 145; St. Louis Acad. Sci. Trans., vol. 1, p. 684.

1861. Hall, James, Report of the superintendent of the Geological Survey of Wisconsin. Reports the determination of the quartzitic character of the rocks about Spirit [Devils] Lake and refers them to the Huronian. Considers as Clinton the limestone below the limestone which he designates the Racine limestone in the eastern part of the State. Describes new species of fossils.

1862. Hall, J., and Whitney, J. D., Report on the geological survey of the State of Wisconsin, vol. 1. Hall discussed the rock formations of the eastern part of the State and Whitney those of the lead-bearing region in southwestern Wisconsin. Whitney presents a map of the Driftless Area and discusses the absence of drift and bowlders and the presence of other superficial deposits. The differentiation of the several sedimentary formations as shown by cross sections and the nomenclature is approximately the same as presented in subsequent reports on the region.

1863. Hall, James, Contributions to paleontology principally from investigations made during the years 1861 and 1862: State Cab. Nat. Hist. [N. Y.] 16th Ann. Rept. Preliminary notice of the fauna of the Cambrian sandstone with remarks on previously known species of fossils and description of some new ones from the sandstone of the upper Mississippi Valley. Discusses the equivalence of the Cambrian sandstone of the upper Mississippi Valley with the Potsdam sandstone of New York.

1864. Winchell, A., Notice of a small collection of fossils from the Potsdam sandstone of Wisconsin and Lake Superior sandstone of Michigan: Am. Jour. Sci., 2d ser., vol. 37, pp. 226–232. Includes some fossils from sandstone overlying the Baraboo quartzite.

1866. Bliss, J. S., Notes on Wisconsin drift: Am. Jour. Sci., 2d ser., vol. 41.

1867. Whittlesey, Charles, On the fresh-water glacial drift of the Northwestern States: Smithsonian Contr. to Knowl., vol. 15, art. 2. Gives a general description of the drift, grouping the deposits in three members—(1) Coarse unstratified drift on the uplands, (2) finer, partly stratified drift, (3) ashen, blue, and red laminated clays. He assumes it to be settled that the moving force in the drift epoch was glacier ice. Describes the Kettle moraine topography east of Lake Winnebago and refers the depressions to the melting of buried ice masses. Reports drift copper from Madison, Ripon, Kenosha, and Walworth counties. Cites Lapham as reporting wood from depth of 18 feet in Walworth County. Reports the following shells from yellowish compact clay and hardpan 12 to 24 feet above the lake at Milwaukee: *Planorbis campanulatus, Paludina decisa, Melania depygus, Lymnea desidiosa, Cyclas similis.* Illustrates crossing glacial striæ on Niagara dolomite near Sheboygan lighthouse.

Whittlesey, Charles, On the ice movements of the glacial era in the valley of the St. Lawrence: Am. Assoc. Adv. Sci. Proc., vol. 15, pp. 43–54. Discusses glacial movements across Wisconsin and other States, and cites locations and bearings of striæ.

1869. Andrews, Edmund, On some remarkable relations and characters of the western bowlder drift: Am. Jour. Sci., 2d ser., vol. 48, pp. 172–179. Refers to buried soil near Beloit, Wis. States that "another characteristic of the western drift is that as a whole it is beyond all question a stratified water deposit." Describes the Kettle moraine as thrown up by violent water action, opposing the theory that it is a glacial moraine.

1870. Andrews, Edmund, The North American lakes considered as chronometers of postglacial time: Chicago Acad. Sci. Trans., vol. 2, art. 1.

1872. Eaton, J. H., Report on the geology of the region about Devils Lake, Wis.: Wisconsin Acad. Sci. Trans., vol. 1, pp. 124–128. Regards the quartzite as metamorphosed Potsdam sandstone and the elevation of the ridge as preglacial. Refers to Lapham's suggestion that Baraboo River once flowed through the Devils Lake gorge and states that this gorge is due to widening of a fissure, later blocked with drift.

Irving, R. D., On the age of the quartzites, schist, and conglomerates of Sauk County, Wis.: Wisconsin Acad. Sci. Trans., vol. 1, pp. 129–137, 1872; also Am. Jour. Sci., 3d ser., vol. 3, pp. 93–99. Presents evidence of unconformity between the quartzite and the Cambrian sandstone.

Knapp, J. G., Ancient lakes of Wisconsin: Wisconsin Acad. Sci. Trans., vol. 1, pp. 151–153. General speculations on some supposed ancient lakes.

1873. Irving, R. D., Note on the age of the metamorphic rocks of Portland, Dodge County, Wis.: Am. Jour. Sci., 3d ser., vol. 5, pp. 282–286. The first public announcement seems to have been made by I. A. Lapham in a lecture at Milwaukee in February, 1848. Argues that the quartzite is "Azoic" or "Primary" and lies unconformably below the Cambrian. The rocks are similar to those regarded as Huronian.

Eaton, J. H., On the relations of the sandstones, conglomerates, and limestones of Sauk County, Wis., to each other and to the Azoic: Am. Jour. Sci., vol. 5, pp. 444–447. Presents evidence of unconformity between the Cambrian sandstone and the quartzite.

1874. Chamberlin, T. C., Some evidences bearing upon the method of the upheaval of the quartzites of Sauk and Columbia counties: Wisconsin Acad. Sci. Trans., vol. 2, pp. 129–132.

Chamberlin, T. C., On the fluctuation in level of the quartzites of Sauk and Columbia counties: Wisconsin Acad. Sci. Trans., vol. 2, pp. 133–138.

Eaton, J. H., Relations of the sandstones, conglomerates, and limestone of Baraboo Valley to each other and to the Azoic quartzites: Wisconsin Acad. Sci. Trans., vol. 2, pp. 123–727.

1875. Irving, R. D., Note on some new points in the elementary stratification of the primordial and Canadian rocks of south-central Wisconsin: Am. Jour. Sci., 3d ser., vol. 9, pp. 440–443. Announces the differentiation of the Madison sandstone and Mendota limestone.

Nicholson, H. A., On the Guelph limestones of North America and their organic remains: Geol. Mag., new ser., vol. 2, pp. 343–348. Refers to limestone at Racine as though belonging to the Guelph.

1876. Warren, Maj. G. K., Report upon the improvement of the water transportation route from the Mississippi to Lake Michigan along the Wisconsin and Fox rivers: Ann. Rept. Chief Engineers, 44th Cong., 2d sess., H. Ex. Doc. 1, pt. 2, vol. 2, pp. 189–298.

1877. Chamberlin, T. C., Geology of eastern Wisconsin: Geology of Wisconsin, survey of 1873–1877, vol. 2, pp. 91–405, map in atlas. Detailed description of the drift and underlying formations. (See numerous references in present report.)

Irving, R. D., Geology of central Wisconsin: Geology of Wisconsin, survey of 1873–1877, vol. 2, pp. 407–636, map in atlas. Detailed description of the drift and underlying formations. (See numerous references in present report.)

Lapham, I. A., Report of progress and results for the year 1873: Geology of Wisconsin, survey of 1873–1877, vol. 2, pp. 5–44, map in atlas. Gives table of railroad elevations. In a catalogue of minerals he cites fragments of meteoric iron from Washing-

ton County, marcasite in drift clays, magnetite in sand along shore of Lake Michigan, glauconite (?) in sandstone near Madison, celestite in drift clay at Wauwatosa, stalactites in cave in Dane County, travertine in Sauk County, tufa at many springs, cerusite at Blue Mounds, asphaltum in some small cavities in the Devonian limestone near Milwaukee and east of Fond du Lac, and peat in many bogs. Gives analyses of artesian and spring waters.

Lapham, I. A., Report of progress and results for the year 1874: Geology of Wisconsin, survey of 1873–1877, vol. 2, pp. 45–66, maps in atlas. Presents log of the artesian well in Capitol Park, Madison, and log of well at Kilbourne. Reports discovery of native copper and silver in the well at Kilbourne City at depth of 516 feet in Archean rock. Reports identification of Madison sandstone in lower part of what was regarded as Lower Magnesian limestone. Names Mendota limestone below. Summarizes results of Professor Chamberlin's survey of eastern Wisconsin.

Strong, Moses, Geology and topography of the lead region: Geology of Wisconsin, survey of 1873–1877, vol. 2, pp. 645–752, maps in atlas. Gives brief description of drift in Green County with detailed discussion of older formations here and throughout the lead region with maps. (See references in present report.)

Woodman, E. C., The pipestone of Devils Lake: Wisconsin Acad. Sci. Trans., vol. 5, pp. 251–254.

Wright, O. W., Report of progress and results for the year 1875: Geology of Wisconsin, survey of 1873–1877, vol. 2, pp. 27–89. Discusses the age of the cement rock at Milwaukee, referring it on stratigraphic evidence to the water-lime group of the "Lower Helderberg." Chamberlin and Whitfield had determined it on fossil evidence to belong to the Hamilton.

1878. Chamberlin, T. C., On the extent and significance of the Wisconsin kettle moraine: Wisconsin Acad. Sci. Trans., vol. 4, pp. 201–234. Discusses surface features, structure, and composition; sources of material, relations to drift movements, makes tentative correlation with moraines in other States, discusses significance of the moraine as a datum line of reference in Quaternary history, suggests that the moraine marks a secondary period of glaciation, with an interval of deglaciation between it and the epoch of extreme advance.

Claypole, E. W., On the preglacial geography of the region of the Great Lakes: Canadian Naturalist, vol. 8, new ser., pp. 187–206. Refers to possible preglacial stream in Green Bay–Lake Winnebago trough and to a possible buried southward outlet from Lake Michigan.

Dana, J. D., On the driftless interior of North America: Am. Jour. Sci., 3d ser., vol. 15, pp. 250–255. Discusses briefly the Driftless Area in Wisconsin and holds that it is probable that the Driftless Area was located to a large degree by the climate.

1878. Day, F. H., On the fauna of the Niagara and Upper Silurian rocks as exhibited in Milwaukee County, Wis., and in counties contiguous thereto: Wisconsin Acad. Sci. Trans., vol. 4, pp. 113–125.

Irving, R. D., Origin of the driftless region of the northwest: Am. Jour. Sci., 3d ser., vol. 15, pp. 313–314. Note on the originality of his theory that the Driftless Area was due to the deflecting influence of the Lake Michigan, Green Bay, and Lake Superior depressions.

Irving, R. D., Driftless region of Wisconsin: Am. Jour. Sci., 3d ser., vol. 15, pp. 406–407. Note giving to T. C. Chamberlin credit for the first recognition of the great moraines in Wisconsin as such and their great value as indicators of the positions and size of the various glaciers and of glacial movements generally.

1879. Chamberlin, T. C., and Strong, Moses, Wisconsin: Macfarlane's Am. Geological Railway Guide, pp. 139–144. Indicates the geologic formations in the vicinity of each railway station.

Upham, W., Terminal moraines of the North American ice sheet: Am. Jour. Sci., 3d ser., vol. 18, pp. 81–92, 197–209. Refers to the Wisconsin moraines described by Chamberlin.

1880. Chamberlin, T. C., Le Kettle moraine et les mouvements glaciaires qui lui ont donné naissance: Cong. géol. internat., sess. 1878, Compt. rend., Paris, pp. 254–268.

Iriving, R. D., The mineral resources of Wisconsin: Am. Inst. Min. Eng. Trans., vol. 8, pp. 478–508, with colored maps. Summarizes results of Wisconsin Geological Survey on mineral resources.

1882. Buell, I. M., The corals of Delafield: Wisconsin Acad. Sci. Trans., vol. 5, pp. 185–193. Describes fossils from the "Cincinnati" shale (Maquoketa) at Robert's quarry, south of Pewaukee Lake.

Chamberlin, T. C., Observations on the recent glacial drift of the Alps: Wisconsin Acad. Sci. Trans., vol. 5, pp. 258–270. Compares glacial drift phenomena of the Alps with those of eastern Wisconsin.

Chamberlin, T. C., The bearing of some recent determinations on the correlation of the eastern and western terminal moraines: Am. Jour. Sci., 3d ser., 24, pp. 93–97. Makes incidental reference to moraines in Wisconsin.

Sweezy, G. D., On some points in the geology of the region about Beloit: Wisconsin Acad. Sci. Trans., vol. 5, pp. 194–204. Discusses the stratigraphy, refers to the preglacial valley of Rock River, and to glacial striæ at Beloit.

1883. Chamberlin, T. C., The terminal moraine west of Ohio: Science, vol. 2, pp. 317–318. Refers to the determination that the Potash Kettle Range in eastern Wisconsin is an interlobate glacial moraine and not a beach line.

Chamberlin, T. C., Preliminary paper on the terminal moraine of the second glacial period: U. S. Geol. Survey Third Ann. Rept., pp. 291–402. Describes the moraines of eastern Wisconsin and the correlated moraines on the east and west, with maps. (See numerous references in the present paper.)

1883. Chamberlin, T. C., General geology; soils and subsoils; building material; artesian wells: Geology of Wisconsin, survey of 1873-1879, vol. 1. Discusses the chemical, lithological, and historical geology of the State. Discusses in considerable detail the geologic work in Wisconsin between the Devonian and glacial periods. Subdivides the "Quaternary age or glacial period" into (1) First glacial epoch, (2) Interglacial epoch, (3) Second glacial epoch, (4) "Champlain" or lacustrine epoch (5) Terrace or fluviatile epoch. (See numerous references in present paper.)

Hall, James, Contributions to the geological history of the American continent: Am. Assoc. Adv. Sci. Proc., vol. 31, pp. 29-69. Address of retiring president delivered in 1857. Refers to the geologic formations of eastern Wisconsin.

Irving, R. D., On the nature of the induration in the St. Peters and Potsdam sandstones and in certain Archean quartzites in Wisconsin: Am. Jour. Sci., 3d ser., vol. 25, pp. 401-411. Describes the deposition of interstitial quartz in the Baraboo quartzite and the rejuvenation of the quartz crystals composing the grains in saccharoidal sandstone of the "Potsdam" and St. Peter formations.

Salisbury, R. D., Chemical analyses compiled: Geology of Wisconsin, survey of 1873-1879, vol. 1, pp. 303-308.

Wadsworth, M. E., The Potsdam and St. Peters sandstones: Science, vol. 2, p. 52. Note on Irving's article.

1884. Chamberlin, T. C., The terminal moraines of the later epoch [abstract]: Am. Assoc. Adv. Sci. Proc., vol. 32, pp. 211-212. Refers to the moraines in Wisconsin and their extensions east and west, also to the origin of the basins of the Great Lakes.

Davis, W. M., The distribution and origin of drumlins: Am. Jour. Sci., 3d ser., vol. 28, pp. 407-416. Refers to the drumlins of Wisconsin.

Davis, W. M., Drumlins: Science, vol. 4, pp. 418-420.

Johnson, H. A., and Thomas, B. W., Organisms in bowlder clays of Chicago: Am. Jour. Sci., 3d ser., vol. 28, pp. 317-318. Report the detection of macrospores of ærogenous plants in the clay and in its embedded fragments of shale along the shore of Lake Michigan from Kenosha, Wis., to the Indiana line.

Walcott, C. D., The Cambrian system of the United States and Canada [abstract]: Washington Phil. Soc. Bull., vol. 6, pp. 98-102. Refers to correlation of the Wisconsin Cambrian.

1885. Chamberlin, T. C., Report [on work on Quaternary geology]: U. S. Geol. Survey Fifth Ann. Rept., pp. 20-24. Reports briefly on field investigations in Wisconsin.

Chamberlin, T. C., Report of glacial division: U. S. Geol. Survey Sixth Ann. Rept., pp. 33-40. Reports on studies of glacial phenomena in Wisconsin.

Chamberlin, T. C., and Salisbury, R. D., Preliminary paper on the Driftless Area of the upper Mississippi Valley: U. S. Geol. Survey Sixth Ann. Rept., pp. 199-322. (See references in present paper.)

Irving, R. D., and Van Hise, C. R., On secondary enlargements of mineral fragments in certain rocks: U. S. Geol. Survey Bull. 8. Describes the enlargement of quartz fragments in sandstones from certain localities in south-central Wisconsin and the origin of the quartzites from the deposition of interstitial quartz.

McGee, W J, Map of the United States, exhibiting the present status of knowledge relating to the areal distribution of geologic groups (preliminary compilation): U. S. Geol. Survey Fifth Ann. Rept., explanation, pp. 34-38.

1886. Salisbury, R. D., Notes on the dispersion of drift copper: Wisconsin Acad. Sci. Trans., vol. 6, pp. 42-50. (See references in present paper.)

1887. Hitchcock, C. H., Geological map of the United States and part of Canada: Am. Inst. Min. Eng. Trans., pp. 465-488. Shows geology of Wisconsin.

Chamberlin, T. C., An inventory of our glacial drift: Am. Assoc. Sci. Proc., vol. 35, pp. 195-211.

1888. Chamberlin, T. C., Report of division of glacial geology: U. S. Geol. Survey Seventh Ann. Rept., pp. 76-85. Report on studies of glacial phenomena in Wisconsin.

Chamberlin, T. C., The rock scorings of the great ice invasions: U. S. Geol. Survey Seventh Ann. Rept., pp. 174-248. Presents a map of the earlier and later drift sheets and of glacial striæ. Describes the abrasive work of the Pleistocene glaciers, taking some of his illustrations from southeastern Wisconsin.

1889. Chamberlin, T. C., Report of division of glacial geology: U. S. Geol. Survey Eighth Ann. Rept., pt. 1, pp. 141-144. Reports on studies of glacial phenomena in Wisconsin.

Chamberlin, T. C., Report of division of glacial geology: U. S. Geol. Survey Ninth Ann. Rept., pp. 84-87. Reports on studies of glacial phenomena in Wisconsin.

1890. Chamberlin, T. C., Report of division of glacial geology: U. S. Geol. Survey Tenth Ann. Rept., pt. 1, p. 21. Reports on studies of glacial phenomena in Wisconsin.

Chamberlin, T. C., Irving, R. D., and Strong, Moses, Wisconsin: Macfarlane's geological railway guide, 2d ed., pp. 223-232. Indicates the geologic formations in the vicinity of each railway station.

1891. Chamberlin, T. C., Report of division of glacial geology: U. S. Geol. Survey Eleventh Ann. Rept., pt. 1, pp. 74-76. Reports on studies of glacial phenomena in Wisconsin.

Chamberlin, T. C., Report of division of glacial geology: U. S. Geol. Survey Twelfth Ann. Rept., pt. 1, p. 89. Reports on studies of glacial phenomena in Wisconsin.

Salisbury, R. D., On the northward and eastward extension of pre-Pleistocene gravels in the basin of the Mississippi: Am. Geologist, abstract, vol. 8, p. 238, 1891; also Geol. Soc. America Bull., vol. 3, pp. 183-186.

1892. Bierbauer, Bruno, A check list of Paleozoic fossils of Wisconsin, Minnesota, Iowa, Dakota, and Nebraska: Minnesota Acad. Nat. Sci. Bull., vol. 3, pp. 206–247.

Buell, I. M., Geology of the Waterloo quartzite area: Wisconsin Acad. Sci. Bull., vol. 9, pp. 255–274. (See references in the present paper.)

Chamberlin, T. C., Report of division of glacial geology: U. S. Geol. Survey Thirteenth Ann. Rept., pt. 1, pp. 121–122. Reports on studies of glacial phenomena in Wisconsin.

Salisbury, R. D., On the northward and eastward extension of the pre-Pleistocene gravels of the Mississippi basin: Geol. Soc. America Bull., abstract, vol. 3, pp. 183–186.

Wahnschaffe, Felix, Mittheilungen über das Glacialgebeit Nordamerikas. I, Die Endmoränen von Wisconsin und Pennsylvania: Deutsche geol. Gesell. Zeitschr., Band 44, Heft 1, pp. 107–122. Describes the drift and terminal moraines in Wisconsin and Pennsylvania; considers that the terminal moraine does not mark the southern limit of glaciation; compares the terminal moraines of Europe and America.

1893. Arey, A. L., Preliminary notice of the discovery of strata of the Guelph formation in Rochester, N. Y.: Rochester Acad. Sci., vol. 2, pp. 104–107. Describes the outcrop of the formation and gives a table comparing its fauna with those of the Guelph dolomite of the Canadian Survey, the Wisconsin Survey, and other writers.

Chamberlin, T. C., Report of division of glacial geology: U. S. Geol. Survey Fourteenth Ann. Rept., pt. 1, pp. 193–194. Reports on studies of glacial phenomena in Wisconsin.

Chamberlin, T. C., Some questions respecting glacial phenomena about Madison: Am. Geologist, abstract, vol. 12, p. 176.

Chamberlin, T. C., The horizon of drumlin, osar, and kame formation: Jour. Geology, vol. 1, pp. 255–267, 1893; Am. Geologist, abstract, vol. 12, pp. 122–123. Defines the term "englacial" and describes the movements of englacial material from the bottom of the ice sheet to limited heights and the agent of its transportation. Describes the drumlin area of Wisconsin and the bowlder trains and bowlder belts of Ohio, Indiana, and Illinois. Concludes that the osars and kames of the latter region are basal material.

Emmons, S. F., From Chicago to the Mississippi River, itinerary: Cong. géol. internat. 5th sess., Compt. rend., pp. 367–374.

Gilbert, G. Karl, From the Ohio to the Mississippi River, general sketch: Cong. géol. internat. 5th sess., Compt. rend., pp. 289–290.

Mead, D. W., The geology of Wisconsin water supplies, 1893. A paper read before the convention of the American Waterworks Association at Milwaukee, Wis., Sept. 5–9.

Van Hise, C. R., Some dynamic phenomena shown by the Baraboo quartzite ranges of Wisconsin: Jour. Geology, vol. 1, pp. 347–355. Describes the dynamic phenomena and the changes which the quartzite has undergone in passing from a massive quartzite showing little evidence of movement to rocks that have been fractured and cleaved and finally to a rock that is apparently a crystalline schist.

1894. Chamberlin, T. C., Glacial phenomena of North America: The great ice age, by James Geikie, 3d ed., ch. 41, pp. 724–775.

Hobbs, W. H., On a recent diamond find in Wisconsin and on the probable origin of this and other Wisconsin diamonds: Am. Geologist, vol. 14, pp. 31–35.

Kunz, G. F., Topaz from Texas: Am. Jour. Sci., 3d ser., vol. 47, pp. 403–404. Gives the crystallographic measurements of topaz and remarks on the characters of a diamond from Wisconsin.

Kunz, G. F., Mineralogical notes: N. Y. Acad. Sci. Trans., vol. 13, pp. 144–145. Notes on topaz from Texas and diamonds from Wisconsin.

Taylor, F. B., A reconnaissance of the abandoned shore lines of Green Bay [Michigan and Wisconsin]: Am. Geologist, vol. 13, pp. 316–327.

Upham, Warren, The Madison type of drumlins: Am. Geologist, vol. 14, pp. 69–83. Describes drumlins with nucleal stratified sand in Massachusetts and gives a more detailed description of similar hills in the vicinity of Madison, Wis.

1895. Buell, I. M., Bowlder trains from the outcrops of the Waterloo quartzite area: Wisconsin Acad. Sci. Trans., vol. 10, pp. 485–509. (See references in the present paper.)

Chamberlin, T. C., Report of division of glacial geology: U. S. Geol. Survey Fifteenth Ann. Rept., pp. 179–180. Reports on studies of glacial phenomena in Wisconsin.

Hall, C. W., and Sardeson, F. W., The magnesian series of the northwestern States: Geol. Soc. America Bull., vol. 6, pp. 167–198. Discusses the lithologic and paleontologic characteristics of the series in Minnesota, Iowa, Wisconsin, and Illinois.

Hobbs, W. H., A contribution to the mineralogy of Wisconsin: Wisconsin Univ. sci. ser., vol. 1, pp. 109–156. Gives a list of papers on the subject and describes the mineralogic characters of quartz, arsenopyrite, calcite, smithsonite, galena, cerusite, sphalerite, gypsum, barite, marcasite, pyrite, azurite, malachite, and diamonds.

Kunz, G. F., Precious stones: U. S. Geol. Survey Sixteenth Ann. Rept., pt. 4, pp. 595–605. Notes the occurrence of diamonds in Wisconsin; also that of other precious stones in other parts of the United States.

Salisbury, R. D., Preglacial gravels on the quartzite range near Baraboo, Wis.: Jour. Geology, vol. 3, pp. 655–667. Describes the character of the deposits and names the fossils found in the pebbles. Discusses the evidence as to the age of the gravels and their relation to the high-level gravels of adjacent States.

Taylor, F. B., Niagara and the Great Lakes: Am. Jour. Sci., 3d ser., vol. 44, pp. 249–270. Refers to ancient lake phenomena in Lake Michigan basin in Wisconsin in connection with the general discussion.

Van Hise, C. R., The origin of The Dells of the Wisconsin: Wisconsin Acad. Sci. Trans., vol. 10, pp. 556–560. Discusses control of the stream by joints in the sandstone.

Weidman, Samuel, On the quartz keratophyre and associated rocks of the north range of the Baraboo Bluffs [Wisconsin]: Wisconsin Univ. sci. ser., vol. 1, pp. 35–56. Gives a geologic map of the region and describes the areal geology and the occurrence and microscopic characters of the quartz keratophyre.

Whitfield, R. P., Republication of descriptions of fossils from the Hall collection in the American Museum of Natural History, from the report of progress for 1861 of the Geological Survey of Wisconsin, by James Hall, with illustrations from the original type specimens not heretofore figured: Am. Mus. Nat. Hist. Mem., vol. 1, pt. 2.

1896. Hershey, O. H., Preglacial erosion cycles in northwestern Illinois: Am. Geologist, vol. 18, pp. 71–100.

Salisbury, R. D., Loess in Wisconsin drift formation: Jour. Geology, vol. 4, pp. 929–937. Describes the characters and relations of loess and drift beds in Wisconsin.

Van Hise, C. R., A central Wisconsin base level: Science, new ser., vol. 4, pp. 57–59.

1897. Salisbury, R. D., and Atwood, W. W., Drift phenomena in the vicinity of Devils Lake and Baraboo, Wis.: Jour. Geology, vol. 5, pp. 131–147.

Weller, Stuart, *Cryptodiscus* Hall: Jour. Geology, vol. 5, pp. 803–808. Describes material from the Niagara dolomite of Wisconsin and discusses its correlation with *Callicrinus*.

1898. Buckley, E. R., On the building and ornamental stones of Wisconsin: Wisconsin Geol. and Nat. Hist. Survey Bull. 4.

Eastman, C. R., Dentition of Devonian Ptyctodontidæ: Am. Naturalist, vol. 32, pp. 473–488, 545-560. Describes material from the State quarry of Iowa and discusses the relations of the Devonian fish fauna of Milwaukee, Wis.

Weidman, Samuel, A contribution to the geology of the pre-Cambrian igneous rocks of the Fox River valley, Wis.: Wisconsin Geol. and Nat. Hist. Survey Bull. 3.

Weller, Stuart, Description of Devonian crinoids and blastoids from Milwaukee, Wis.: New York Acad. Sci. Annals, vol. 11, pp. 117–124.

1899. Hobbs, W. H., Emigrant diamonds in America: Pop. Sci. Monthly, vol. 56.

Monroe, C. E., and Teller, E. E., The fauna of the Devonian formation at Milwaukee, Wis.: Jour. Geology, vol. 7, pp. 272–283. Describes occurrence of the Devonian strata and gives list of fossils collected.

Walcott, C. D., U. S. Geol. Survey Twentieth Ann. Rept., pt. 1, p. 54. Reports on studies of glacial phenomena in Wisconsin.

1900. Bruncken, Ernest, Physiographical field notes in the town of Wauwatosa [Wisconsin]: Wisconsin Nat. Hist. Soc. Bull., new ser., vol. 1,

Buckley, E. R., Tests of Wisconsin building stone: Jour. Geology, vol. 8, pp. 526–567.

Hubbard, G. D., The Blue Mound quartzite [Wisconsin]: Am. Geologist, vol. 25, pp. 163–168.

Monroe, C. E., A notice of a new area of Devonian rocks in Wisconsin: Jour. Geology, vol. 8, pp. 313–314. Describes occurrence of Devonian rocks on the shore of Lake Michigan.

Salisbury, R. D., and Atwood, W. W., The geography of the region about Devils Lake and The Dalles of the Wisconsin, with some notes on its surface geology: Wisconsin Geol. and Nat. Hist. Survey Bull. 5, new ser., No. 1. Review: Am. Geologist, vol. 26, pp. 252–253. Describes the physiography, the general character, and distribution of the Paleozoic formations, the development of erosion features, and the glacial history and deposits of the region.

Teller, E. E., The Hamilton formation at Milwaukee, Wis.: Wisconsin Nat. Hist. Soc. Bull., new ser., no. 1, pp. 47–56.

Walcott, C. D., U. S. Geol. Survey Twenty-first Ann. Rept., pt. 1, pp. 85–86. Reports on studies of glacial phenomena in Wisconsin.

1901. Buckley, E. R., The clays and clay industries of Wisconsin: Wisconsin Geol. and Nat. Hist. Survey Bull. 7. Describes the composition, classification, and properties of clays and the occurrence and distribution of clay deposits in Wisconsin.

Buckley, E. R., Ice ramparts: Wisconsin Acad. Sci. Trans., vol. 13.

Collie, G. L., Physiography of Wisconsin: Am. Bur. Geog. Bull., vol. 2, pp. 270–287. Gives a general discussion of the several physiographic provinces of the State.

Sardeson, F. W., The lower Silurian formations of Wisconsin and Minnesota compared: Minnesota Acad. Sci. Bull., vol. 3, pp. 319–326.

Walcott, C. D., U. S. Geol. Survey Twenty-second Ann. Rept., pt. 1, p. 75. Reports on studies of glacial phenomena in Wisconsin.

1902. Fenneman, N. M., On the lakes of southeastern Wisconsin: Wisconsin Geol. and Nat. Hist. Survey Bull. 8.

Hobbs, W. H., Emigrant diamonds in America: Reprinted in Smithsonian Inst. Ann. Rept. for 1901, pp. 359–366. Describes the occurrence of diamonds in glacial materials, principally in Wisconsin.

Walcott, C. D., U. S. Geol. Survey Twenty-third Ann. Rept., pp. 33–34. Reports on studies of glacial phenomena in Wisconsin.

1903. Rohn, Oscar, The Baraboo iron range [Wisconsin]: Eng. and Min. Jour., vol. 76, pp. 615–617.

Upham, Warren, Glacial Lake Nicolet and the portage between the Fox and Wisconsin rivers: Am. Geologist, vol. 32, pp. 105–115.

Upham, Warren, Glacial Lake Jean Nicolet: Am. Geologist, vol. 32, pp. 330–331.

1903. Walcott, C. D., U. S. Geol. Survey Twenty-fourth Ann. Rept., p. 36. Reports on studies of glacial phenomena in Wisconsin.

Weidman, Samuel, The pre-Potsdam peneplain of the pre-Cambrian of north-central Wisconsin: Jour. Geology, vol. 11, pp. 289–313. Describes physiographic features and general structure of the peneplain, and discusses its formation, evidences as to its age, and its subsequent history.

1904. Alden, W. C., The Delavan lobe of the Lake Michigan glacier of the Wisconsin stage of glaciation and associated phenomena: U. S. Geol. Survey Prof. Paper 34. (See references in present paper.)

Hille, F., The Baraboo iron ore: Eng. and Min. Jour., vol. 77, p. 875.

Walcott, C. D., U. S. Geol. Survey Twenty-fifth Ann. Rept., pp. 32–33. Reports on the studies of glacial phenomena in Wisconsin.

Weidman, Samuel, Iron ores of Wisconsin, with special reference to the Baraboo district: Wisconsin Engineer, vol. 9, pp. 31–45.

Weidman, Samuel: The Baraboo iron-bearing district of Wisconsin: Wisconsin Geol. and Nat. Hist. Survey Bull. 13. Describes the occurrence, megascopic and microscopic characters, and geologic relations of pre-Cambrian igneous rocks and sedimentary strata, and gives a general account of Cambrian and Ordovician sedimentary rocks and glacial drift deposits, and discusses the ground water and the occurrence, character, and origin of the iron-ore deposits.

Winchell, N. H., The Baraboo iron ore: Am. Geologist, vol. 34, pp. 189–192. Discusses Weidman's report on the Baraboo iron-bearing district of Wisconsin.

1905. Alden, W. C., The drumlins of southeastern Wisconsin: U. S. Geol. Survey Bull. 273. (See references in present paper.)

Eckel, E. C., Cement materials and industry of the United States: U. S. Geol. Survey Bull. 243, pp. 329–330, 354–355. Discusses Portland cement and natural cement resources of Wisconsin.

Kirchoffer, W. G., The sources of water-supply in Wisconsin: Wisconsin Univ. Bull., Eng. ser., vol. 3, pp. 163–249. Includes a general account of the geology and drill records of many wells. (See references in present paper.)

Schultz, Alfred, Underground waters of eastern United States; Wisconsin district: U. S. Geol. Survey Water-Supply Paper 114, pp. 233–241. Describes briefly the topography, general geology, and underground-water resources.

Walcott, C. D., U. S. Geol. Survey Twenty-sixth Ann. Rept., p. 29. Reports on the studies of glacial phenomena in Wisconsin.

Warner, J. H., The Waterloo quartzite: Min. World, vol. 22, No. 16, pp. 420–422.

1906. Case, E. C., A peculiar formation of shore ice: Jour. Geology, vol. 14, pp. 134–137.

Goldthwait, J. W., Correlation of the raised beaches on the west side of Lake Michigan: Jour. Geology, vol. 14, No. 5, pp. 411–424.

1906. Lawson, P. V., Story of the rocks and minerals of Wisconsin, Appleton, Wis.

Ries, H., The clays of Wisconsin and their uses: Wisconsin Geol. and Nat. Hist. Survey Bull. 15. (Includes also a report on molding sands.)

Alden, W. C., Description of the Milwaukee quadrangle, Wis.: U. S. Geol. Survey Geol. Atlas, Milwaukee folio (No. 140).

Teller, E. E., Notes on the fossil fish spine, *Phlyctænacanthus telleri* (Eastman): Wisconsin Nat. Hist Soc. Bull., new ser., vol. 4, October, pp. 162–167. Describes fossil fish spine from beds of Hamilton age near Milwaukee.

Walcott, C. D., U. S. Geol. Survey Twenty-seventh Ann. Rept., p. 16. Reports on the studies of glacial phenomena in Wisconsin.

1907. Case, E. C., Wisconsin, its geology and physical geography; an account of the natural features and climate of the State for students and general readers, Milwaukee.

Case, E. C., A description of models, illustrating the physical geography of Wisconsin: Milwaukee Normal School Bull., vol. 3, No. 3, pp. 1–19.

Cleland, H. F., Restoration of certain Devonian cephalopods with descriptions of new species: Jour. Geology, vol. 15, No. 5, pp. 459–469.

Goldthwait, J. W., The abandoned shore lines of eastern Wisconsin: Wisconsin Geol. and Nat. Hist. Survey Bull. 17. Gives an outline of the history of the Great Lakes during the ice age, reviews previous work, and describes in detail the old shore lines.

Hobbs, W. H., and Leith, C. K., The pre-Cambrian volcanic and intrusive rocks of the Fox River valley, Wisconsin: Wisconsin Univ. Bull. 158, sci. ser., vol. 3, No. 6, pp. 247–277. (See references in present paper.)

Sardeson, F. W., Galena series: Geol. Soc. America Bull., vol. 18, pp. 179–194. Discusses the distribution, relations, and nomenclature of Ordovician formations of the upper Mississippi included in what he designates the Galena series.

Weidman, Samuel, Geology of north-central Wisconsin: Wisconsin Geol. and Nat. Hist. Survey Bull. 16, p. 664. Makes incidental references to the area described in the present paper.

1908. Goldthwait, J. W., A reconstruction of the water planes of the extinct glacial lakes in the Lake Michigan basin: Jour. Geology, vol. 16, pp. 459–476.

Goldthwait, J. W., The altitude of the Algonquin beach and its significance [abstract]: Science, new ser., vol. 28, pp. 382–383.

Goldthwait, J. W., Intercision, a peculiar kind of modification of drainage: School Sci. and Math., vol. 8, No. 2, pp. 129–139. Refers to conditions observed on Pike River at Kenosha.

Mansfield, G. R., The Baraboo region of Wisconsin: Jour. Geography, vol. 6, No. 9, pp. 286–292. Describes the physiographic history of the region.

Mansfield, G. R., Glacial and normal erosion in Montana and Wisconsin: Jour. Geography, vol. 6, No. 10, pp. 306–312. Describes the Crazy Mountains, Montana, and the Baraboo region, Wisconsin, and contrasts the characteristics of glaciated and unglaciated surfaces.

Penhallow, D. P., Some fossil plants from the Middle Devonian of Milwaukee, Wis.: Wisconsin Nat. Hist. Soc. Bull., vol. 6, Nos. 1 and 2, pp. 8-12.

Smith, G. O., U. S. Geol. Survey Twenty-ninth Ann. Rept., p. 28. Reports on the studies of glacial phenomena in Wisconsin.

Smith, L. S., The water powers of Wisconsin: Wisconsin Geol. and Nat. Hist. Survey Bull. 20.

Weidman, Samuel, General petrology of Wisconsin igneous rocks [abstract]: Science, new ser., vol. 27, p. 723.

1909. Alden, W. C., Concerning certain criteria for discrimination of the age of glacial drift sheets, as modified by topographic situation and drainage relations: Jour. Geology, vol. 17, pp. 694-709. Discussion based on character and relations of pre-Wisconsin drift of southern Wisconsin and northern Illinois.

Alden, W. C., The Pleistocene phenomena of southeastern Wisconsin [abstract]: Science, new ser., vol. 29, p. 557.

Cleland, H. F., Some features of the Wisconsin middle Devonic [abstract]: Science, new ser., vol. 29, p. 637.

Smith, G. O., U. S. Geol. Survey Thirtieth Ann. Rept., p. 35. Reports on the studies of glacial phenomena in Wisconsin.

Van Hise, C. R., and Leith, C. K., Pre-Cambrian geology of North America: U. S. Geol. Survey Bull. 360. Discusses the geology of the pre-Cambrian rocks of the Fox River valley and of the Baraboo and Waterloo districts.

1910. Fenneman, N. M., On the lakes of southeastern Wisconsin: Wisconsin Geol. and Nat. Hist. Survey Bull. 8, 2d ed.

Goldthwait, J. W., Isobases of Algonquin and Iroquois beaches and their significance: Geol. Soc. America Bull., vol. 21, p. 232.

Hotchkiss, W. O., A new model of the State of Wisconsin: Philadelphia Geog. Soc. Bull., vol. 8, pp. 65-68.

Martin, Lawrence, The University of Wisconsin models: Philadelphia Geog. Soc. Bull., vol. 8, pp. 27-31. Describes and illustrates new relief maps of Wisconsin and the Baraboo district.

Smith, G. O., U. S. Geol. Survey Thirty-first Ann. Rept., p. 33. Reports on the studies of glacial phenomena in Wisconsin.

Steidtman, Edward, The secondary structures of the eastern part of the Baraboo quartzite range, Wis.: Jour. Geology, vol. 18, No. 3, pp. 259-270. Discusses the relation of the joints and schistosity to the folding.

Teller, E. E., An operculated gastropod from the Niagara formation of Wisconsin: Wisconsin Acad. Sci. Trans., vol. 16, pt. 2, No. 5, pp. 1286-1288.

1911. Alden, W. C., Radiation of glacial flow as a factor in drumlin formation: Geol. Soc. America Bull. [abstract], vol. 22, pp. 733-734.

1911. Cleland, H. F., The fossils and stratigraphy of the middle Devonic of Wisconsin: Wisconsin Geol. and Nat. Hist. Survey Bull. 21, sci. ser., No. 6. (See references in present paper.)

Smith, G. O., U. S. Geol. Survey Thirty-second Ann. Rept., p. 48. Report on the studies of glacial phenomena in Wisconsin.

Teller, E. E., A synopsis of the type specimens of fossils from the Paleozoic formations of Wisconsin: Wisconsin Nat. Hist. Soc. Bull., vol. 9, No. 4, pp. 170-271.

Van Hise, C. R., and Leith, C. K., The geology of the Lake Superior region: U. S. Geol. Survey Mon. 52. Abstract: Washington Acad. Sci. Jour., vol. 1, No. 5, pp. 157-160, October. Discusses the geology of the pre-Cambrian rocks of the Fox River valley and of the Baraboo and Waterloo districts. The Pleistocene geology of the area north of that treated in the present paper is discussed by Lawrence Martin. (See references in text.)

Weidman, Samuel, The glacial lake of Fox River valley and Green Bay and its outlet [abstract]: Science, new ser., vol. 33, p. 467, Mar. 24. States that "the Wisconsin River above Portage was formerly a part of the Fox River system, and through the development of the lake outlet was captured by the lower Wisconsin, a tributary of the Mississippi."

Whitbeck, R. H., Contrasts between the glaciated and the driftless portions of Wisconsin: Philadelphia Geog. Soc. Bull., vol. 9, No. 3, July, pp. 12-21 (114-123).

1912. Alden, W. C., Sketch of the geological history of Green Lake County, Wis.: School Quart., Berlin, Wis., vol. 3, No. 2, pp. 2-14, March.

Hotchkiss, W. O., and Thwaites, F. T., Map of Wisconsin, showing geology and roads, 1911. (Scale 6 miles=1 inch.) Wisconsin Geol. and Nat. Hist. Survey. Includes a table of the geologic formations and an outline of the geologic history of Wisconsin.

1913. Leverett, Frank, Iowan drift (abstract with discussion by A. P. Coleman): Geol. Soc. America Bull., vol. 24, No. 4, pp. 698-699, Dec. 23. Refers to pre-Wisconsin drift in southern Wisconsin and northern Illinois.

Taylor, F. B., The glacial and postglacial lakes of the Great Lakes region: Smithsonian Inst. Ann. Rept. for 1912, pp. 291-327. Correlates glacial and lake stages of eastern Wisconsin with those farther east.

Weidman, Samuel, The Pleistocene succession in Wisconsin [abstract]: Science, new ser., vol. 37, pp. 456-457, Mar. 21; Geol. Soc. America Bull., vol. 24, No. 4, pp. 697-698, Dec. 23.

Whitbeck, R. H., The geography and industries of Wisconsin: Wisconsin Geol. and Nat. Hist. Survey Bull. 26.

Birge, E. A., and Juday, Chauncey, The inland lakes of Wisconsin: Wisconsin Geol. and Nat. Hist. Survey Bull. 27.

1914. Martin, Lawrence, The physical geography of Wisconsin: Jour. Geography, vol. 12, No. 8, pp. 226–232, April.

Thwaites, F. T., Recent discoveries of "Clinton" iron ore in eastern Wisconsin: U. S. Geol. Survey Bull. 540, pp. 338–342.

Hotchkiss, W. O., and Steidtmann, Edward, Limestone road materials of Wisconsin: Wisconsin Geol. and Nat. Hist. Survey Bull. 34.

1915. Huels, F. W., The peat resources of Wisconsin: Wisconsin Geol. and Nat. Hist. Survey Bull. 45.

1915. Savage, T. E., Alexandrian rocks of northeastern Illinois and eastern Wisconsin [abstract]: Geol. Soc. America Bull., vol. 26, No. 1, p. 95, Mar. 31.

Weidman, Samuel, and Schultz, A. R., The underground and surface water supplies of Wisconsin: Wisconsin Geol. and Nat. Hist. Survey Bull. 35.

Whitbeck, R. H., The geography of the Fox-Winnebago Valley: Wisconsin Geol. and Nat. Hist. Survey Bull. 42.

1916. Martin, Lawrence, The physical geography of Wisconsin: Wisconsin Geol. and Nat. Hist. Survey Bull. 36.

CHAPTER II.—GEOGRAPHY, TOPOGRAPHY, AND DRAINAGE.

GEOGRAPHY.

The area discussed as "southeastern" Wisconsin in this paper consists of all that part of the State lying between the Illinois-Wisconsin line on the south (latitude 42° 30′ N.) and the latitude of the southern part of Oshkosh on the north (latitude 44° N.) and between longitude 90° W. on the west and the west shore of Lake Michigan on the east, an area of approximately 11,090 square miles. According to the census of 1910, this supported a population of 1,085,426, distributed as shown in the tables below. The second table gives the estimated population of the fractional parts of counties only partly included in the area.

Area, in square miles, and population (in 1910) of counties wholly included in "southeastern" Wisconsin.

	Area.	Population.
Marquette	451	10,741
Green Lake	364	15,491
Fond du Lac	720	51,610
Sheboygan	510	54,888
Ozaukee	226	17,123
Washington	423	23,784
Dodge	884	47,436
Columbia	776	31,129
Dane	1,188	77,435
Jefferson	548	34,306
Waukesha	562	37,100
Milwaukee	228	433,187
Racine	323	57,424
Kenosha	274	32,929
Walworth	562	29,614
Rock	706	55,538
Green	576	21,641

Area, in square miles, and population (in 1910) of fractional parts of counties included in "southeastern" Wisconsin.

	Area.	Estimated population.
Manitowoc	121	6,653
Calumet	69	3,884
Winnebago	144	4,304
Waushara	46	1,794
Adams	374	5,226
Juneau	126	2,450
Sauk	498	19,727
Iowa	217	5,081
Lafayette	174	4,931

The total area of the State being 54,450 square miles and the total population in 1910 being 2,333,860, it appears that while the district under discussion comprises but 20⅓ per cent of the area it contains 46.5 per cent of the population. A large part of the most valuable and best-developed lands of the State lies within this area. Taken as a whole, it is a region of fine farms well suited to grain, stock, and dairy farming. Of the population, 488,073, or 44.9 per cent, live in rural districts or in villages of less than 1,000 inhabitants and, for the most part, gain their livelihood directly from the soil. Live stock, dairy products, grain, tobacco, and beet sugar, as well as manufactured products are exported in considerable quantities. The cities on the shore of Lake Michigan (Milwaukee, Racine, Kenosha, Sheboygan, and Port Washington) have good harbors and carry on an extensive lake traffic. The following cities have populations of 10,000 or more:

Cities of more than 10,000 inhabitants (1910).

Milwaukee	373,857
Racine	38,002
Sheboygan	26,398
Madison	25,531
Kenosha	21,371
Fond du Lac	18,797
Beloit	15,125
Janesville	13,894

Besides the fertile soil, which is the most important of the natural resources, the mineral products, of which much is consumed within the area or in the immediately surrounding region and much is exported, are limestone, sandstone, quartzite, and granitic rock used for building and monumental stone, paving blocks, and macadam; lime; natural cement; clay for the manufacture of brick and drain tile; molding sand; sand and gravel for concrete work and road making and for the manufacture of sand brick and cement building blocks and other building material; and iron ore, from a small part of which mineral paint is made. The water resources include, besides the usually plentiful rainfall, artesian waters which supply much of the urban population and manufacturing plants; shallow-well and surface waters which supply the rural population and their live stock; and spring waters, some of which have an extensive market as mineral waters. With these may also be included the developed water powers of the streams. Most of these mineral resources exist in much larger quantities than are now utilized and could supply a much larger demand. The extensive marshes and swamps, for example, contain in many places considerable deposits of peat, of which almost no use is yet being made.

TOPOGRAPHY.

Taken as a whole the topography of the area is that of a plain ranging from flatness, through moderate undulations, to hilly. Nowhere is there any relief approaching the mountainous. The range of elevation is from 581 feet above sea level at the shore of Lake Michigan to 1,730 feet above on top of the higher of the Blue Mounds, near the southern part of the west line of Dane County; the next highest point being Point Sauk, in sec. 15, Greenfield township, Sauk County (T. 11 N., R. 7 E.), on the south range of the Baraboo quartzite, 4 miles east of Devils Lake, which stands 1,640 feet above sea level. The greatest relief within comparatively short distances is between these two high points and Wisconsin River. From the top of West Blue Mound northward to the bottom lands along Wisconsin River, a distance of about 10 miles, the descent is about 1,000 feet, and from Point Sauk south to the river, a distance of 4½ miles, it is about 880 feet. The south quartzite range has a general relief of 500 to 600 feet above the lower lands on the north and south.[1] The next greatest reliefs are probably to be found along the range of hills, known as the Kettle interlobate moraine, or "Kettle Range," which extends southerly from Manitowoc County to Walworth County, and culminates in Holy Hill, in southwestern Washington County, with an elevation of 1,361 feet above sea level and a relief of about 360 feet above the marshy bottom of the valley on the east.[2]

In Fond du Lac County, where the west margin of the Niagara dolomite extends as a mural escarpment along the east side of Lake Winnebago and the plain to the south, the relief varies from 100 to 300 feet. Similar but less conspicuous escarpments mark the west margins of the Lower Magnesian and Trenton limestones in places in Winnebago, Fond du Lac, Green Lake, Columbia, and Sauk counties.[3] In the drift-covered part of the area the general configuration is one of smoothly flowing contours with reliefs rarely greater than 150 feet and generally less. In part of this, especially in the eastern half of Fond du Lac County, the southern half of Dodge County, Jefferson County, and the eastern half of Dane County, there is a notable development of smoothly contoured elliptical hills and elongated ridges known as drumlins, with their nearly parallel, but slightly diverging, longer axes aligned with the directions followed by the moving currents of the last of the great glaciers which traversed the region.[4] With the possible exception of the higher parts of the Kettle interlobate moraine, the terminal moraines of the ancient glaciers, which extend in broadly curving belts across the area (Pl. III, in pocket) are more conspicuous for their geologic significance than as topographic features, even in this region of moderate relief. They are, however, topographically striking where they rise above bordering flat plain tracts, as in Rock and Walworth counties and north of the Baraboo Bluffs in northern Sauk County, southeastern Adams County, and western Waushara County.[5] In these parts the moraines have reliefs of 100 to 150 feet. The striking features of these terminal moraines are, however, not so much their relief as the configuration of their surfaces, which are in many places knolled and pitted in remarkable fashion. More detailed discussion of this configuration is included in the descriptions of the several moraines.

[1] See Baraboo and Denzer topographic maps, U. S. Geol. Survey.

[2] See Oconomowoc, Hartford, West Bend, and Eagle topographic maps, U. S. Geol. Survey.

[3] See Neenah, Fond du Lac, and Ripon topographic maps, U. S. Geol. Survey.

[4] See Fond du Lac, Hartford, Watertown, Whitewater, Waterloo, Koshkonong, and Sun Prairie topographic maps, U. S. Geol. Survey.

[5] See Dells, Briggsville, Evansville, Janesville, Shopiere, and Delavan topographic maps, U. S. Geol. Survey.

Within the limits of the terminal moraines of the later glaciers the topographic development due to stream erosion is very slight. This is owing to the fact that the heavy deposits of drift so deeply covered the ancient topography that the stream courses were readjusted and that the new drainage has not yet had time either to erode new valleys or to clear out the old ones. Thus the streams on the later drift meander for a large part of their courses through extensive marsh and swamp tracts and among drift hills in very shallow trenchlike channels, few of which are more than 15 or 20 feet deep. Even where the maximum excavation of about 100 feet has been accomplished the valleys are little more than narrow V-shaped ravines.

On passing outside the terminal moraines to the area of the older drift between Rock River on the east and the boundary of the Driftless Area on the west in southern Dane County, Green County,[1] and the southeastern part of Lafayette County, the topography of the uplands and slopes is found to be one of mature stream erosion though the bottoms of the valleys are very young. Like those within the later glacial moraines the streams either meander through broad marshes or are only beginning to trench the flat plains of sand and gravel. This condition is the result of a series of events which may be briefly stated. Prior to the incursion of the glaciers the streams of this older-drift area had developed a mature system of dendritic branching valleys similar to those now seen in the Driftless Area. At least one glacial ice sheet, the Illinoian, and possibly a still earlier one, traversed the tract from east to west, and its melting left the eroded surface of the rock mantled with glacial drift varying in thickness from a few inches to 175 feet or more. The run-off from the melting ice and accompanying and subsequent precipitation gathered into streams which, for the most part, followed the earlier, partly buried lines of drainage. In a few places the drift filling was so great that the streams were diverted into new positions, where they encountered rock sills which retarded the reexcavation of the drift. The erosion of the tributaries continued coordinately with the partial reexcavation of the valleys of the master streams, Rock, Sugar, and Pecatonica rivers, until the latter process was interrupted by the flood of detritus-bearing glacial waters issuing from glaciers of the later, or Wisconsin, stage when they invaded the area and halted at the lines marked by the outer terminal moraines. The partial refilling of the valleys of Rock and Sugar rivers and the blocking of the lower part of the Pecatonica Valley in Illinois and of other tributaries in Wisconsin by the deposition of the outwashed glacial sand and gravel, rejuvenated the streams and caused them to meander through marshes whose drainage was blocked by the obstructing drift. The result is a mature topography on the slopes and uplands combined with a very youthful development in the valley bottoms.

Certain small topographic features in this area of the older drift, simulating those developed on a much larger scale in the Driftless Area and indicative of the maturity of erosion on the crests and slopes, are sandstone towers which could not have withstood a glacier and which are hence believed to have been developed by erosion since the glaciation of this part of the area and to indicate that the time since the earlier glacial invasion is considerably greater than that since the incursion of the ice of the Wisconsin stage. (See Pls. XI, *B*, p. 88, and XVI, *A*, p. 140.) These features are considered in more detail on pages 141 and 149.

In the western part of the district, which was never, so far as known, invaded by the continental glaciers and which in consequence is known as the Driftless Area, a still more mature stream-eroded topography is found. Except in the southwestern part of the Cross Plains quadrangle the topographic survey has not been extended over that part of the Driftless Area lying south of Wisconsin River and east of the ninetieth meridian; but such a survey has been made just west of this meridian in both southern Wisconsin and northern Illinois. The Richland Center, Mineral Point, and Elizabeth topographic maps show a topography practically the same in kind and degree of dissection to that of the unsurveyed quadrangles immediately to the east within the area under discussion. Scarcely a single square mile of the original upland plain remains undissected. Practically all has been reduced to slope and in very many places the tips of the erosion lines have notched and lowered the

[1] See Janesville, Brodhead, and Evansville topographic maps, U. S. Geol. Survey.

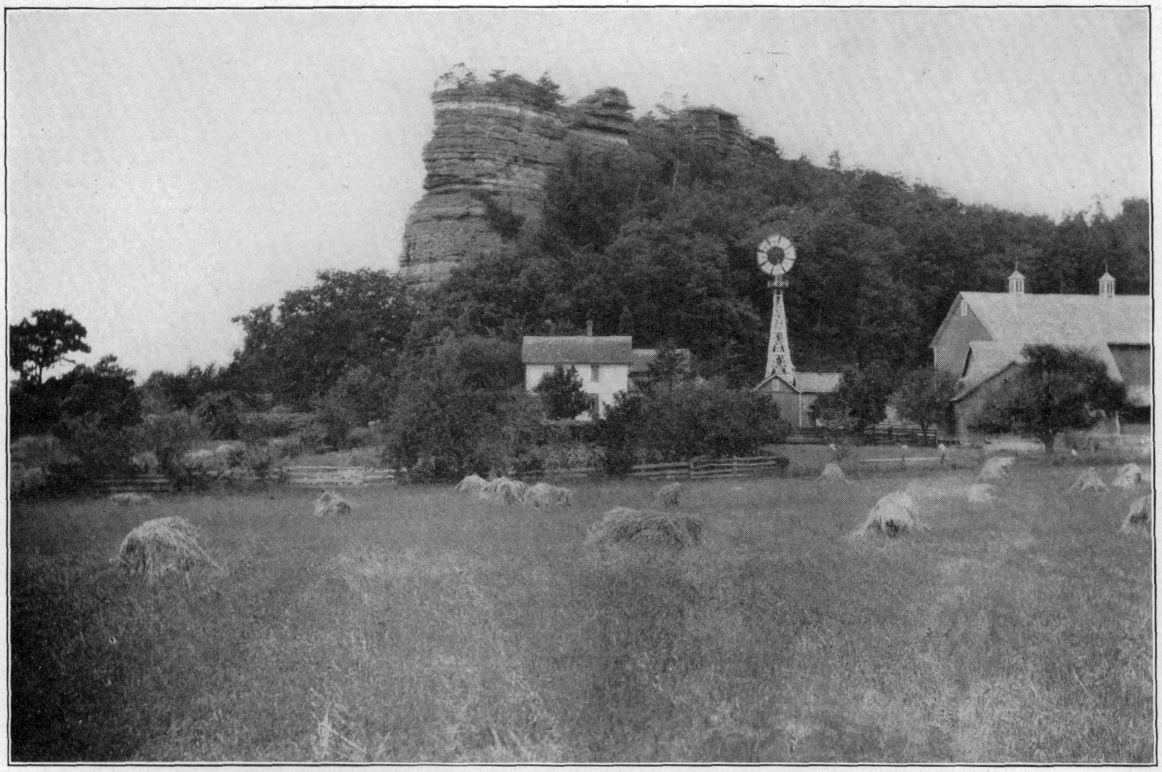
divides between the tributaries of the Wisconsin and the Pecatonica.

Farther east the same is true of the divides between the tributaries of these streams and those of Sugar River. The topography is one of intricately branching ridges alternating with correlative branching valleys. The crest of the main divide, known as Military Ridge, varies somewhat above and below an elevation of 1,200 feet; Wisconsin River near the ninetieth meridian flows about 710 feet above the sea; and Pecatonica River leaves the State at Martintown at an elevation of about 770 feet. There is thus a general relief of 400 to 500 feet in this part of the area, above which West Blue Mound, as already indicated, rises some 500 feet. The crests and slopes, where underlain by limestone, are generally smoothly rounded and not too steep for cultivation (see Pl. XVII, *A*, p. 141), but where the protecting limestone has been cut through, exposing the softer and more friable sandstones to weathering and erosion, the slopes are more abrupt. Along the Wisconsin and tributary valleys they form mural lines of cliffs. (See Pl. VI.) Northward toward the Baraboo quartzite range in the Denzer quadrangle less and less of the limestone remains on the narrowed ridges, and the valleys in the sandstone are broader. In many places salient points of the dividing ridges rise in picturesque castellated forms. (See Pl. V.) Where erosion has detached these from the divides they stand as isolated towers, which finally crumble to low mounds of sandstone, indicative of an advanced stage of erosion. At a point near Denzer these processes have resulted in the formation of a natural bridge.

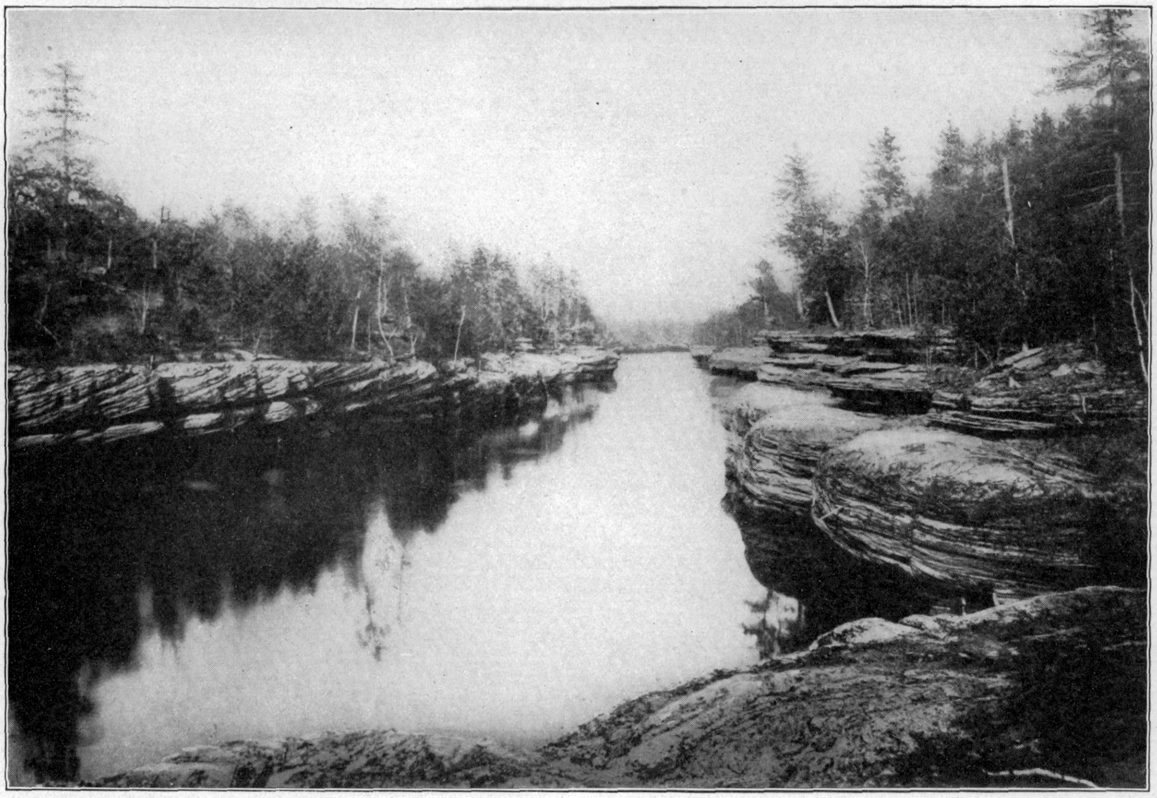
It should be noted that although the Driftless Area was not invaded by the glaciers the valleys in it of the Wisconsin and its tributaries contain considerable thicknesses of detritus, washed into them by the glacial waters during the several stages of glaciation and of silts washed from the adjacent slopes and deposited above the obstructing glacio-fluvial accumulations. The Pecatonica Valley was invaded by the earlier ice to a point 3 miles north of the State line, where it was blocked by a great dam of drift, north of which there must be a considerable thickness of filling. In consequence of this the flat bottom lands bordering these streams are in reality indices of youth in the present streams, which strikingly contrast with the maturity of the topography of the dissected slopes and narrow divides.

North of the Baraboo Bluffs, in the western part of the Dells quadrangle, the ridges are still narrower and are separated from more broken and isolated hills, like Coon Bluff and Elephant Back, by considerable distances. Still farther north, in Juneau, and Adams counties, only a few isolated remnants in the form of castellated bluffs and sandstone towers rise above the extensive plain. Petenwell Rock, at the bridge over the Wisconsin in the town of Necedah, a few miles above the northwest corner of the area under discussion, is an excellent example of these isolated sandstone remnants. The wide separation of these remnants of nearly flat-lying rock formation is indicative of a very advanced stage of erosion, such as is associated with the nearly complete reduction of an upland plain or a region of ridges and hills to a plain or to a newer and lower peneplain of erosion. It is to be noted, however, that the flatness of much of this extensive plain, instead of being the result of long-continued erosion, is due to the fact that minor inequalities, such as low ridges and valleys, are buried under a considerable thickness of glaciofluvial and glaciolacustrine sediments. The conditions under which these sediments were deposited are discussed on pages 226–230.

In this part of the area are The Dalles or Dells of the Wisconsin, which are probably the most famous and beautiful of all the scenic features of the region. (See Pl. V, *B*.) About 2 miles north of the south line of Adams and Juneau counties Wisconsin River leaves the broad, shallow channel in which it has been meandering through the extensive plain to the north and enters a gorge 60 to 120 feet deep and but 54 feet wide in its most constricted part. This gorge it traverses for about 6 miles before emerging in the broad marshy tracts within the terminal moraine below Kilbourn. In its original condition the river rushed between the vertical sandstone walls with considerable velocity. Its flow is now controlled by the dam of the Wisconsin Electric Power Co. at Kilbourn, and the ponding of the waters has submerged some formerly exposed features of the Upper Dells. Crowned with ferns, evergreens, and other arboreal verdure, and reflected in the placid waters, the carved walls present a beautiful picture. Here is Stand Rock, yonder Chimney Rock, there the rounded prows that jut out

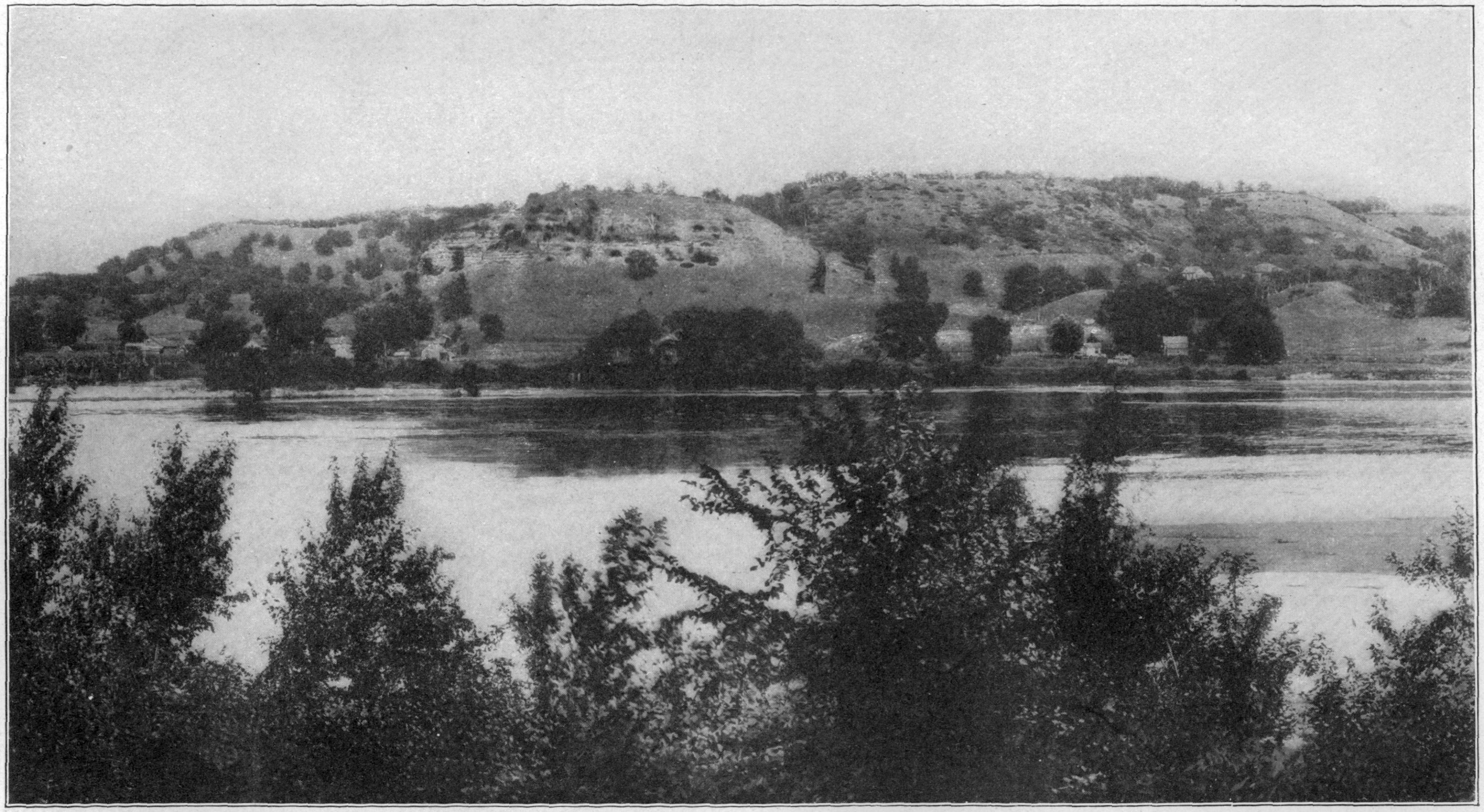


A. TOWER ROCK, A BLUFF OF "POTSDAM" SANDSTONE IN THE DRIFTLESS AREA, 2 MILES SOUTH OF DENZER, WIS.



B. THE DELLS OF THE WISCONSIN.

Photograph by H. H. Bennett.



SANDSTONE BLUFFS BORDERING WISCONSIN RIVER OPPOSITE PRAIRIE DU SAC.

from the "Navy Yard." Steamboat Rock, anchored near the side of the channel, and a similar detached little island in the Lower Dells are veritable gems of decorative fluting. Weird and wonderful are tortuous ravines, such as Witches Gulch, Roodes Glen, Coldwater Canyon, and Artists Glen, cut by tributary streamlets, which have breached the walls of the gorge and which, by the attrition of pebbles whirled in potholes beneath the little waterfalls, have here and there excavated chamber-like recesses whose ascending walls nearly meet beneath the overhanging foliage that shuts out the sunlight. The gorge of Dell Creek, in which lies Mirror Lake, and some of the tributary ravines exhibit features similar to The Dells.

The Baraboo Bluffs, or Baraboo quartzite range, lying within the great bend of Wisconsin River, consists of two ridges extending east and west for about 26 miles. The broader south range varies in width from 1 to 5 miles and in height from 300 to 800 feet. The north range is generally less than 2 miles in width and from 100 to 560 feet in height. The two ridges join at the ends, inclosing a canoe-shaped basin through which flows Baraboo River. The generally smoothly rounded surface of these ridges is partly wooded and partly under cultivation. The north range is cut through by three narrow gorges or water gaps—one, the Upper Narrows, in the vicinity of Ableman, through which Baraboo River enters the inclosed basin; another, that of Narrows Creek, 1 to 2 miles farther west; and a third, the Lower Narrows, 6 miles east of Baraboo, through which Baraboo River escapes to the marshy flats bordering Wisconsin River. (See Pl. XIII, p. 106.) A similar gorge about half a mile in width cuts through the south range south of Baraboo but is blocked at each end by great dams of glacial morainal drift, between which lies the mile-long Devils Lake. The scenery in these gaps through the quartzite ranges is the nearest approach to mountainous in the whole region. The height and abruptness of the bluffs, the mingling of tints of purplish quartzite and green verdure, and the structural relations of tilted and upturned beds with unconformities and basal conglomerate, combine in features of more than ordinary interest to both tourist and scientific student. Nor should the picturesque beauty of Parfrey and Dorward glens, in the lower south slope of the south range east of Devils Lake, or the remarkable development of the basal conglomerate there exposed, be overlooked.

DRAINAGE.

RIVERS.

SYSTEMS.

The drainage of the area under discussion is tributary to two of the great systems of the continent, the Great Lakes-St. Lawrence system and the Mississippi system. The waters of the former are gathered by Sheboygan, Milwaukee, Root, and Pike rivers and other small streams flowing into Lake Michigan, and by Fox and Fond du Lac rivers and minor streams flowing to Lake Winnebago. The waters of the Mississippi system are gathered by Wisconsin River and its tributaries (Lemonweir and Baraboo rivers, Dell, Honey, Black Earth, and smaller creeks), by Rock River and its tributaries (Sugar and Pecatonica rivers and Turtle Creek), and by Des Plaines and Fox rivers, tributaries of Illinois River.

The Continental Divide is in few places a marked topographic feature. In southeastern Adams County it is formed by the range of hills constituting the terminal moraine. In Columbia County it lies in the lowlands and marshes between the Wisconsin and the Fox in the region of Portage, and is scarcely perceptible until it reaches the upland north of Cambria. It is said that before the construction of levees and the control of the flow in the Fox-Wisconsin canal flood waters from the larger stream sometimes crossed the divide through the marshes and escaped by way of the Fox. The divide crosses the gently rolling upland underlain by the Galena dolomite and the Trenton limestone in Green Lake and Fond du Lac counties, passes between the slightly separated marshes in Oakland Township, at the head of the Horicon basin, and surmounts the Niagara escarpment. Thence passing southeastward to and across the great moraines in northern Washington County it continues southward along minor ridges through Waukesha, Racine, and Kenosha counties, leaving the State a few miles west of the shore of Lake Michigan. East of Union Grove, in southern Racine County, it crosses a continuous through valley in a marsh between the heads of

Des Plaines and Root rivers, in which it is scarcely perceptible.

The areas of the drainage basins within the district under discussion are approximately as shown in the table below.

Area, in square miles, of the drainage basins of southeastern Wisconsin.

Great Lakes-St. Lawrence (34 per cent):	
Lake Michigan	2,100
Fox River and Lake Winnebago	1,765
Mississippi River (66 per cent):	
Wisconsin River	1,555
Rock River	3,700
Sugar River	620
Pecatonica River	540
Fox River	800
Des Plaines River	125

All the larger streams of the area, except the headwaters of Pecatonica River, are very young, having been established, or reestablished, subsequent to the incursion of the Pleistocene glaciers. Part of these follow the ancestral courses of preglacial streams, but most of them now flow, in some parts of their courses, through new and more or less distant channels. Some of the shifts amount to many miles, so that in places the present streams flow on top of hundreds of feet of glacial filling, and in other places, after cutting through a thin coating of drift, flow over rock sills in which they are eroding new channels. To the retardation consequent on this rock cutting and to the comparative shortness of time since the establishment of the present streams is due in large measure the imperfections of the drainage shown by the large acreage of marsh and swamp lands and the considerable number of lakes.

WISCONSIN RIVER.

Wisconsin River is the largest stream of the State. Only about 100 miles of the middle part of its course, however, and about 13 per cent of its total drainage area of 11,850 square miles is included within the area under discussion. This portion includes the great bend where the stream swings about the eastern end of the Baraboo range and changes its direction from southerly to southwesterly. The city of Portage stands on its banks near the apex of this bend. This point has long been one of great interest in the development of the State because of the remarkable closeness with which Fox River here approaches Wisconsin River. The Fox, heading in the northeastern part of Columbia County, flows westward until within about 1¼ miles of the Wisconsin, then turns northward in a broad marshy tract which borders both streams and extends continuously between them, and proceeds northeastward in a winding course to Lake Winnebago, which it enters near Oshkosh. These two streams, with the lower Fox, between Lake Winnebago and Green Bay, thus form a nearly continuous waterway, with an easy portage, from the Great Lakes to the Mississippi and the Gulf of Mexico. In his final report on the improvement of the water transportation route from the Mississippi to Lake Michigan, along Wisconsin and Fox rivers Maj. Gen. G. K. Warren [1] gives an interesting summary of the early historical accounts of this transportation route, with summaries of the various surveys and recommendations for improvements, together with the results of his own surveys. Quoting from John G. Shea [2] with certain interpolations and omissions, he says that Sieur Joliet was appointed to take charge of an expedition for "the discovery of a passage to the South Sea" and that Pere Marquette was selected to accompany him. They left the Mission of St. Ignatius at Michilimackinac on May 17, 1673.

The expedition reached Maskoutens on the 7th of June, which place was supposed by Marquette to be the limit of the previous discoveries of the French. This was probably the vicinity of the present village of Roslin, as Marquette says it was 3 leagues from the Wisconsin. According to the narrative of Maj. Long's expedition to the source of the Saint Peters River in 1823, the league of Marquette and Hennepin is 2¾ English miles.

On "the 10th of June," Marquette says, "two Miamis, whom they [the Indians] had given us as guides, embarked with us, in the sight of a great crowd, who could not wonder enough to see seven Frenchmen alone, in two canoes, dare to undertake so strange and hazardous an expedition.

"We knew that there was, 3 leagues from Maskoutens, a river emptying into the Mississippi; we knew, too, that the point of the compass we were to hold to reach it was west-southwest; but the way is so cut up by marshes and little lakes that it is easy to go astray, especially as the river leading to it is so covered with wild oats that you can hardly discover the channel. Hence we had good need of our two guides, who led us safely to a portage of 2,700 paces and helped us to transport our canoes to enter

[1] The improvement of the water-transportation route from the Mississippi to Lake Michigan, along the Wisconsin and Fox rivers: Chief of Engineers Ann. Rept., 44th Cong., 2d sess., H. Doc. 1, pt. 2, pp. 189-298, 1876.

[2] Discovery and explorations of the Mississippi Valley, 1853.

this river, after which they returned, leaving us alone in an unknown country, in the hands of Providence.

* * * * *

"The river on which we embarked is called Meskousing [Wisconsin]; it is very broad, with a sandy bottom, forming many shallows, which render navigation very difficult. It is full of vine-clad islets. On the banks appear fertile lands diversified with wood, prairie, and hill. Here you find oaks, walnut, whitewood, and another kind of tree with branches armed with long thorns. We saw no small game or fish, but deer and moose in considerable numbers.

"Our route was southwest, and after sailing * * * 40 leagues on this same route, we reached the mouth of our river, and * * * safely entered the Mississippi on the 17th of June, with a joy that I can not express."

A monument in the southern part of the city of Portage, near the fair grounds, now marks the point where Joliet and Marquette launched their canoes on the waters of the Wisconsin.

Marquette's characterization of the Wisconsin as "very broad, with sandy bottom, forming many shallows, which render navigation very difficult" describes it well as it is to-day. This might also apply to that part of the stream above Portage excepting where constricted at The Dells. The great quantity of shifting sand is the chief obstacle to all permanent improvement of the channel for navigation. The construction of a series of wing dams to control the current and promote scouring of the channel was carried on at intervals up to 1887, when it was discontinued.

The fall, as measured between Portage and the Mississippi by Gen. Warren's survey,[1] varied from 0.095 foot to 3.698 feet per mile, with a general average of about $1\frac{1}{2}$ feet per mile, the elevation at the mouth being 625 feet above sea level and at Portage 180 feet higher. The writer has not at hand the figures showing the fall above Portage, but except in The Dells, the average slope is probably not far from that below Portage. In The Dells the fall is somewhat greater. The effect of the constricted gorge on the flood waters is considerable. Gen. Warren [2] says: "The effect of this contraction is such as to restrain the floods, so that they are said sometimes to rise 50 feet above low water in the valley above, while the same flood will rise not to exceed 10 feet in the valley below."

The character of the valley in its several parts is the result of a series of notable changes and of an interesting history which is detailed on pages 105–111, 169–172, 215–217, 222–230, 244–246.

FOX RIVER (WISCONSIN).

Except for about 23 miles below Eureka, the whole course of Fox River above Lake Winnebago lies within the area under discussion.

Of the condition of upper Fox River in 1866 Gen. Warren [3] says, abstracting from his report of 1867:

The present traveled route between Oshkosh and Fort Winnebago is 104 miles, the air line being 54 miles. As near as can be estimated there have been 18,000 feet of cut-offs by dredging, making a saving of about three-fifths of the distance. The total fall is about 33.1 feet. In most places there is a fall of a foot in $2\frac{1}{2}$ miles, but there are long reaches where the fall is scarcely perceptible. Several lakes occur in the course which are generally shallow and full of wild rice.

Of Lake Puckaway he says:[4]

Lake Puckaway is a sheet of water $8\frac{1}{2}$ miles long and from 1 to 2 miles wide. The lower end of the lake is very shallow and full of reeds and wild rice. A channel running northeast from Marquette has been cut through for steamers. It is from 3 to $3\frac{1}{2}$ feet deep. A channel having 4 feet of water leads along the eastern shore of the lake. The bottom of the lake is very soft, black mud, through which a channel of any depth can be easily dredged. For about a mile to the westward of Marquette the lake is filled with rushes. A channel exists, however, which has about $4\frac{1}{2}$ feet of water. After getting out of the rushes there is from 5 to 6 feet of water to the end of the lake.

Of the canal and the relations of the Fox and Wisconsin at Portage he says:[5]

It [the canal] is cut through a flat sandy plain which separates the waters of the Fox from those of the Wisconsin. The Fox River is about 5 feet lower than the Wisconsin in ordinary stages of water. During high water the Wisconsin overflows this neck of low ground at Portage, and also 5 or 6 miles above, and a large portion of its waters are thus diverted to Green Bay. The spring rise in the Fox is principally due to this cause, for the Fox itself fluctuates very little. About 7 miles below Portage a stream called Big Slough [Neenah Creek] comes into the Fox. During high water this connects with the Wisconsin and becomes a very considerable stream, bringing a large volume of water into the Fox. In fact, the greater part of the low country between the two rivers is overflowed by the Wisconsin at this time.

In places above and below Portage levees have been constructed to prevent this flooding of the lowlands by the Wisconsin. The construction of locks and dredging on the Fox maintains a navigable channel from Portage to Lake Winnebago.

[1] Op. cit., p. 263.
[2] Idem, p. 254.
[3] Idem, p. 235.
[4] Idem, p. 236.
[5] Idem, p. 238.

ROCK RIVER.

Rock River is really the principal stream of the area, for it drains a very large part of the central and southern portions. This stream and its tributaries in Wisconsin, including Turtle Creek, gather the run-off from about 3,700 square miles of land, to which may be added the 620 square miles drained by Sugar River and the 540 square miles drained by Pecatonica River, all of which enters Rock River only a few miles south of the Illinois State line. This is a total of approximately 4,860 square miles, or nearly 44 per cent of the area under discussion.

Near Fort Atkinson Rock River receives the waters of Bark River and its tributary, Scuppernong Creek. These streams head in springs issuing from the gravel hills of the Kettle interlobate moraine and receive the outflow of several of the lakes of the Oconomowoc region. Gathering the waters of the uplands underlain by the Galena dolomite and the Trenton limestone and of a part of the tract east of the Niagara escarpment, Rock River wanders through the marshes and among the drumlins until it is joined at Jefferson by Crawfish River, which follows a similar course through the tract immediately to the west. Behind the dam of drift formed by the terminal moraines which block the ancient valley north of Janesville the waters spread out in Lake Koshkonong, a broad, shallow body of water 2 to 3 miles wide and about 6 miles long. Escaping from this lake the river has cut through the drift and channeled the crests of two buried rock ridges. About 4 miles southwest of Edgerton the stream is joined by Yahara (Catfish) River, which brings the outflow of the four lakes of the Madison region. Passing the moraines the stream regains the ancient valley north of Janesville, but, finding this valley filled to a depth of several hundred feet with sand and gravel outwashed from the ancient glaciers, it followed a course so near the west valley slope that when it had cut down through the drift filling it encountered several salients of the buried rock slope and was forced to cut new channels through them. The maximum depth of the valley through the moraine and the bordering outwash deposits is about 150 feet. This depth decreases with the lowering of the surface of the outwash plain until it is about 60 feet at the Illinois State line at Beloit.

From the State line southward Rock River flows in the ancient filled valley to a point about 7 miles below Rockford, Ill., at which place, after receiving the waters of Kishwaukee River from the east, it leaves the broad old valley (which is completely filled with drift a few miles farther south) and traverses an alternation of narrow rock gorges and broader portions resulting from the erosion of the drift filling buried valleys.

Near the State line the river is joined by Turtle Creek, which heads behind the moraines of the Delavan lobe of the Lake Michigan glacier. Traversing a broad outlet through the moraine west of Delavan and through the bordering outwash deposits this stream flows through a rock gorge north of Clinton Junction and channels the filling in the ancient valley of Rock River until it joins the main stream.

PECATONICA RIVER.

From the dissected slopes of the southern part of the Driftless Area the run-off gathers into Pecatonica River. This stream meanders through the flat bottom of a partly filled valley to a point 2 miles south of Browntown. At this place the broad valley ends abruptly against a dam of glacial drift, and the stream flows through a narrow gorge cut in the limestone at one side. Beyond, the valley again broadens only to be closed at the State line by a second drift dam, which it evades by a new rock cut at Martintown. Thence southeastward to Ridott, Ill., 8 miles east of Freeport, the writer has not traversed the valley. From Ridott to Rockton, about 4 miles southwest of Beloit, the stream meanders widely through a broad alluvial plain, where there is probably a large amount of filling, in an ancient valley bottom. At Rockton the stream cuts through the glacial gravels which have blocked the mouth of the valley and joins Rock River.

SUGAR RIVER.

Sugar River drains a portion of the southeastern part of the Driftless Area and a large part of the area of the older glacial drift north of the Wisconsin State line. The slopes are thus moderately mature, but the bottom of the valley contains so much filling, partly earlier, partly later, that the stream has accomplished little in the way of reexcavation. It meanders widely in a shallow channel cut partly in a broad alluvial plain, partly in glacial sands and gravels, and partly in a marsh, due to the blocking of the Pecatonica Valley, which it enters about 5 miles south of the State line.

FOX RIVER (ILLINOIS).

Heading in the northern part of Waukesha County, Fox River, which is tributary to Illinois River, receives the outflow of Pewaukee Lake and at Waukesha enters an ancient, partly filled valley, which has been designated the preglacial Troy Valley. This valley it traverses, cutting through gravel terraces and meandering through a broad marsh to the vicinity of Mukwanago. At the latter place, after cutting through a drift ridge, the stream turns abruptly eastward along a second marshy valley (another portion of the ancient blocked watercourse) to Big Bend. Turning again southward and passing a third broad marshy tract the stream enters a morainal belt of gravel hills, which it traverses to the Wisconsin State line. At Burlington the Fox is joined by a small stream, White River, bringing the outflow from Lakes Geneva and Como and the spring waters from the bordering moraines.

DES PLAINES RIVER.

That part of Des Plaines River within the area north of the Illinois-Wisconsin State line is very insignificant. It lies between two of the Lake Border morainal ridges, occupying a marshy-bottomed sag, which, farther north, is drained by Root River. The divide in the marsh between the two streams is scarcely perceptible.

SHEBOYGAN RIVER.

The northeastern part of the area is mostly drained to Lake Michigan by Sheboygan River, whose two main branches head in the marsh and swamp tracts west of the glacial moraines. One branch crosses the moraine belt in the vicinity of Glenbeulah. Sheboygan Swamp probably occupies the upper part of an ancient valley which drained eastward, for wells in the vicinity of Elkhart Lake show a considerable depth of glacial drift below the level of the lake. The present stream, instead of following the ancient course, turns northward toward Kiel and cuts through thin drift to a limestone ledge, the rim of the ancient valley, which has interfered with the draining of the swamp. The stream crosses a second limestone ledge at Rockville. Turning southeastward it crosses the morainal belt to the plain of the red till and joins the other branch near Sheboygan Falls. Plunging over a ledge of dolomite, the combined stream meanders through the flat bottom of a rather deep, sharply eroded valley developed at a stage when the waters of Lake Michigan stood at a higher level. The lower course of Pigeon River, a small stream entering the lake a few miles farther north, is similarly terraced. By dredging, the lower part of Sheboygan River has been converted into a harbor, whence considerable lake traffic is carried on. A similar harbor has been made in the mouth of a small stream entering the lake at Port Washington.

MILWAUKEE RIVER.

In consequence of the north-south trend of the lines of elevation in much of the lake-border region, the streams, instead of following the general slope of the surface directly eastward to the lake, flow for considerable distances nearly parallel to the lake shore and reach it eventually only by taking transverse courses at points where the continuity of the ridges is broken. Some of the streams reach the lake only after a series of shifts from one parallel valley to another.

These features are well illustrated by the course of Milwaukee River. This stream rises in Fond du Lac and Sheboygan counties in a number of nearly parallel southward-flowing streams. At West Bend the Milwaukee turns abruptly eastward. After passing Newburg it swings northward and then resumes its eastward course. Near Fredonia, when within 9 miles of the lake, it bends sharply to the right and flows southward, almost parallel to the lake shore, for more than 30 miles, to its debouchure at Milwaukee. Throughout the greater part of this distance its channel is within 3 miles, and at some points is within less than 1 mile, of the lake shore. This somewhat anomalous course is due to the scarcity of east-west transverse valleys through the parallel ridges bordering the lake. Not till the valley of Menominee River was reached at Milwaukee could the stream get through to the lake. Except in the last 5 or 6 miles of its course its valley is generally broad, with slopes that are gentle and but little modified by erosion. The stretch covered by the lower 5 or 6 miles is sharply cut by erosion. Certain changes (see p. 333) have taken place in the lower course of this stream. Its fall in the last 18 miles of its course is about 4 feet per mile. The stretch comprising the lower $2\frac{1}{2}$ miles—that is, the part below the Milwaukee dam—is utilized as a harbor. As this part of the river receives a large portion of the city sewage, it has been found necessary to flush the current in order to carry off the contaminated water. For this purpose a 12-foot tunnel has been constructed from a point 2 miles north of the harbor entrance through the intervening hill to the river just below the dam. Through this tunnel, by means of a 14-foot propeller wheel, 500,000,000 gallons of lake water may be driven every 24 hours. This addition to the river volume is effective in keeping the waters fairly active.

Menominee River has its origin in the southeastern part of Washington County, whence it flows southeasterly to Wauwatosa. From Wauwatosa it flows eastward for 2 miles, then turns abruptly southward for 1 mile and again eastward for 3 miles to its confluence with Milwaukee River, three-fourths of a mile from the harbor entrance. The Menominee is a small stream, ordinarily but a few yards in width, except where widened and deepened in its lower course by dredging for harbor purposes. Above the mouth of Underwood Creek the slopes are gentle and the valley is not greatly modified by erosion. From this point to the lake the valley is of an erosional type, cutting across the topographic trend with abrupt slopes rising in places 100 feet or more above the valley bottom. In its lower 3 miles, east of the National Soldiers' Home, the valley averages one-half mile in width and has a flat, marshy bottom. Except in this lower part the gradient of the stream is high, the fall being 270 feet in 25 miles, an average of 10.8 feet per mile. A special sewage pumping works on Jones Island assists in the discharge into the lake.

Kinnikinnic River is a small stream, 5 or 6 miles long, in the southern part of Milwaukee. As this stream receives a large part of the sewage of the southern part of the city it is flushed with water drawn from the lake through a tunnel extending under that part of the city known as Bayview.

ROOT AND PIKE RIVERS.

The courses of Root and Pike rivers also have been controlled by the north-south trend of the lake border drift ridges. Their lower parts lie within the highest of the ancient beaches of the lake, and the positions and elevations of their mouths have shifted with the shifting waters of the lake. (See pp. 331–333 and 340.) Dredging in the lower courses has afforded harbors for considerable lake traffic.

LAKES.

DISTRIBUTION.

As will be seen by reference to the large map (Pl. III, in pocket) all the lakes of the area lie within the tract that was covered by the glaciers of the Wisconsin stage of glaciation. Lakes are evidences of youth in the development of the drainage systems of a region. They are in a sense temporary, for unless the natural course of stream development be interfered with by other agents or forces in time every square mile of surface will be drained through the development of a mature system of dendritic branching valleys. Attention has been called (see pp. 31 and 32) to the existence of such a mature system in the Driftless Area. So also it was shown that a somewhat less mature system has been developed where the earlier drift mantles the preglacial topography. In neither of these portions of the area are there any lakes. If such existed, as they undoubtedly did in certain places, they have long since been drained by the erosion of the barriers which retained them. Within the area of the later drift sheets, however, many lakes and marshes exist in inclosed basins produced by the blocking of the ancient valleys by drift deposits or by the inequalities of the surface of the drift left by the melting ice; and the streams are so young that they have scarcely begun the excavation of the valleys which will in time, if no change prevents, drain the whole area and cause the lakes and marshes to disappear.

The lakes of southeastern Wisconsin have been described and their origin explained by

N. M. Fenneman[1] in a beautifully illustrated bulletin of the Wisconsin Geological and Natural History Survey, to which readers are referred for more detailed discussion of the phenomena developed along the shores of these lakes. The same survey has issued a series of hydrographic maps showing the submerged contours and environs of nine of the larger lakes of this area.[2]

The origin and the geologic relations of the several lakes will be more clear after the consideration of the preglacial topography of the area and the glacial history, but it may be well to point out the salient features in connection with the description of the lakes.

Taken altogether the lakes of southeastern Wisconsin are of very great value to the State. They attract thousands of visitors from neighboring States with money to spend, besides affording beautiful sites for summer homes and for the recreation of thousands of the State's own citizens. Their contribution to the health and happiness of the people is an asset whose value is not easily computed. They yield abundant fish and a vast ice harvest which contributes to the health and comfort of thousands who never see the lakes.

LAKE WINNEBAGO.

Lake Winnebago, the largest in the State, has a north-south length of approximately 28 miles and a maximum east-west width of about 10 miles, in the latitude of Oshkosh. Something less than half its expanse lies within the area under discussion. To the east rises the drift-mantled escarpment formed by the west edge of the Niagara dolomite and the underlying shale formation, 200 to 300 feet in height. To the west, north, and south lies a drift plain, which is nearly flat near the lake but which rises gradually and within a few miles becomes moderately rolling. The outlet of the lake at Neenah and Menasha, at the west side of the north end, is through two shallow channels over limestone sills. Numerous wells drilled on land opposite the north end of the lake at points less than 50 feet above the water level are reported to have penetrated drift to depths varying from 100 to 275 feet before encountering rock, and numerous wells drilled on the plain east and south of the city of Fond du Lac opposite the south end of the lake at points less than 50 feet above the lake level are also said to have penetrated 100 to 255 feet of drift. There can therefore be little doubt that the lake overlies an ancient valley, which was so completely filled with drift that there is now a maximum of but 20 feet of water in the lake. The conditions under which the glacial ice melted, and the presence of an ancient, poorly developed shore line at a level corresponding to that of the portage between Fox and Wisconsin rivers, indicate that for a time during the progress of deglaciation of the area the lake waters stood about 50 feet higher than at present and discharged to Wisconsin River by way of Fox River (reversed). It is also probable that previous to this stage and for a shorter time the waters were held up to a somewhat higher level over the plain surrounding Fond du Lac and found an outlet through a sag in the surrounding drift ridge at the point where the ridge is cut through by Fond du Lac River, and escaped to a lake in the Horicon basin and thence to Rock River. (See also pp. 324 and 325.)

PUCKAWAY, GREEN, AND RUSH LAKES.

West of Lake Winnebago, in southwestern Winnebago County and Green Lake County, three lakes, Puckaway, Green, and Rush, extend northeast and southwest. The most southwesterly, Lake Puckaway, is merely a shallow expansion of Fox River, and has already been described in connection with that stream (p. 35). On the south side this lake is bordered by drumloidal drift hills and a hill of crystalline rock rising nearly 200 feet above the water level. On the north is a low sandy plain, and on the east are broad marsh tracts that pass gradually into the open water of the lake. There is thus little topographic evidence of a definite valley to which the location of the lake is due. The records of wells drilled on the lake shore and to the west, however, indicate that the lake and the river to the west lie in the line of an ancient valley excavated deeply in the Cambrian sandstone. So completely is this valley filled, however, with glacial drift and silt that the present lake basin is but a few feet in depth. D. E. Brewer, of Berlin, informed the writer

[1] Fenneman, N. M., On the lakes of southeastern Wisconsin: Wisconsin Geol. and Nat. Hist. Survey Bull. 8, 1902; second and revised edition, 1910.

[2] Map No. 1, Lake Geneva; No. 2, Elkhart Lake; No. 3, Lake Beulah; No. 4, Oconomowoc-Waukesha lakes; No. 6, Delavan and Lauderdale lakes; No. 7, Green Lake; No. 8, Lake Mendota; No. 9, Big Cedar Lake; No. 10, Lake Monona.

that he drilled a well at the Chicago or Nee Pee Nauk club house, on the north shore of the lake, to a depth of 330 feet in unconsolidated sand and clay without reaching the rock bottom of the ancient valley, which thus lies more than 500 feet lower than the top of the rock hill on the south side of the lake. Undoubtedly the presence of the lake is due to the incomplete filling of this ancient valley and the obstruction of the outlet by glacial drift. The continuation of this valley, which Fox River leaves by flowing northward from Lake Puckaway, is evidently the trough extending northeastward in which lie Green and Rush lakes.

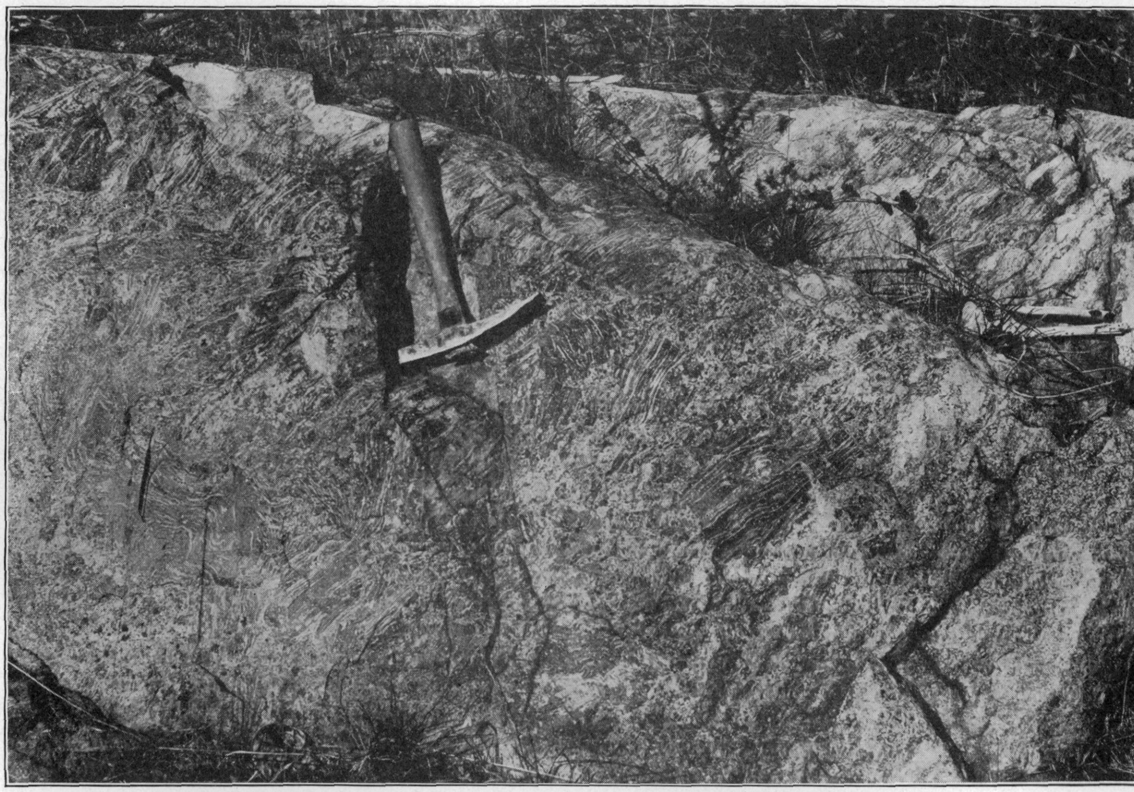
Northeast of the marsh tract at the east end of Lake Puckaway and beyond a ridge, whose knobbed and pitted surface shows it to be a glacial marginal moraine, lies the beautiful basin of Green Lake. This lake, according to measurements cited by Fenneman,[1] has a length of 7.40 miles, a width of 2 miles, an area of 11.5 square miles or 7,360 acres, and a maximum depth of 237 feet. As shown by the hydrographic map, the larger part of the basin west of Lucas Point has a depth of 200 feet or more, a broad bottom, and very abrupt sides. The lake shallows gradually to less than 10 feet near the eastern end. The beautiful green color from which the lake takes its name is due to the depth and purity of the water, most of which comes from springs. To the south the upland, underlain by the Trenton and Lower Magnesian limestones and the St. Peter sandstone, rises 150 to 200 feet above the level of the lake. To the north lie a broad, drift-mantled ridge of rock and a few separated hills. The slopes decline rather steeply, in places forming low bluffs of limestone and sandstone on the lake shore, and elsewhere abutting on rather low shores that afford excellent building sites for the numerous summer cottages and hotels. At the west end is the retaining dam of morainal drift, and from the east end the marsh-bottomed valley continues northeastward. At Lucas Point the abrupt picturesque bluff is composed of 30 feet of Madison sandstone overlain by 50 feet of Lower Magnesian limestone. Farther east the dip of the formations brings the limestone down to the level of the beach. To the southwest the Mendota limestone rises above the beach near Mr. W. T. Runal's place on the shore of Dickinson Bay. These formations also compose Sugar Loaf and the adjacent hill on the north side of the lake.

[1] Op. cit., 2d ed., p. 177.

The relations show clearly that Green Lake is due to blocking of an ancient valley by the ridge of morainal glacial drift at the west end. The valley extends parallel to the direction of the glacial advance, and it is quite possible that its depth was increased by the glacial abrasion of the soft sandstone. The final melting of the ice left the trough blocked by the marginal moraine. There can be little, if any, doubt that the obstructing ridge is entirely of glacial drift, although, so far as the writer ascertained, none of the wells drilled upon it have penetrated to depths greater than 62 feet. In none of these was bedrock encountered. The melting ice did not leave so much filling in the valley to the east as beneath the Puckaway basin to the west, so that Green Lake is much the deeper, being, in fact, the deepest lake in southeastern Wisconsin. The original level of the lake has been somewhat lowered by erosion of the outlet at Dartford, but the construction of a dam at this place has stopped this process.

One of the most interesting features in the vicinity of Green Lake is Mitchells Glen. At this place, which is three-fourths mile from the east end of the south shore of the lake, the side of the valley is a cliff of 100 feet of St. Peter sandstone overlain by 30 to 40 feet of Trenton limestone. An intermittent stream plunging over the bluff at this point in a series of cascades has eroded the sandstone, so as to form a very picturesque little glen. Other beautiful ravines cut the escarpment which extends northeastward along the south side of the valley to the vicinity of Ripon. One of the wells in this valley, that of Mr. H. F. Wilke, NW. $\frac{1}{4}$ sec. 24, Brooklyn Township (T. 16 N., R. 13 E.), about 2 miles from the east end of Green Lake, is said to have penetrated a bed of black vegetal matter, leaves, etc., beneath 100 feet of glacial drift.

Farther northeast along this valley, at the crossing of the railway from Ripon to Rush Lake Junction, is another glacial moraine, beyond which lies the shallow, marsh-bordered basin of Rush Lake. A third moraine traversed by a road closes the basin and separates it from a broad marsh tract on the east. At



A. RHYOLITE BRECCIA EXPOSED IN PRE-CAMBRIAN LEDGES 1½ MILES SOUTHWEST OF MARQUETTE, GREEN LAKE COUNTY, WIS.

B. EAST BLUFF, DEVIL'S LAKE GORGE, SHOWING GREAT TALUS ACCUMULATION OF QUARTZITE BLOCKS.

the north side of this marsh is a fourth ridge of morainal débris, this one of red drift, which undoubtedly for a time retained a lake where now there is marsh. The erosion of the outlet through the red drift ridge at Waukau, however, has drained the basin and its reclamation is being concluded by the growth of marsh vegetation. This latter process, which is one of nature's methods of reclaiming submerged areas, is also reducing the expanse of water in Rush and Puckaway lakes.

LITTLE GREEN, MARIA, EMILY, FOX, AND BEAVER DAM LAKES.

South of Green Lake five small lakes, Little Green, Maria, Emily, Fox, and Beaver Dam, separated by intervals of 1 to 6 miles, lie in reentrants in the margin of the Trenton limestone that are undoubtedly due to preglacial erosion. The basins of Emily and Fox lakes are clearly due to morainal drift dams on the west, formed at the same time as that retaining Green Lake. Lake Maria may be due to the same cause, though it is not so plainly evident. Little Green Lake may lie in a basin excavated in the St. Peter sandstone by glacial erosion at a place where that formation is locally thickened. This is suggested by the absence of any clearly recognizable drift dam and by the fact that the uneven surface of the Lower Magnesian limestone, discovered by the removal of the enveloping sandstone, rises in hills in the midst of the valley to the west of the lake.

Beaver Dam Lake is an irregular curved body of water 11 miles long and having a maximum width of about 2½ miles. It is said to be very shallow and the lake is maintained by an artificial dam at the outlet. It is probable, however, that it marks the position of a partly filled preglacial valley, for a well at the foundry near its south end is said by J. V. Roller, driller, to have penetrated 140 feet of unconsolidated material before reaching bedrock. The artesian well at the woolen mill, about 80 rods farther south, is said to have reached sandstone at a depth of 30 feet, and the Trenton limestone lies near the surface in the city east of the lake. It is interesting to note that in this case the closing of the basin was due not to marginal morainal glacial deposits but to an elongated ridge of ground moraine drift, a drumlin.

DEVILS LAKE.

One of the most interesting, though one of the smaller, lakes of the area is Devils Lake, which lies in the gorge through the south range of the Baraboo quartzite south of Baraboo. This lake, according to measurements made by H. E. Cole, H. E. French, G. K. McConnell, and F. T. Thwaites, in 1908, and recorded on an unpublished map, of which the writer received a blue print, has a length of 1¼ miles, an average width of 0.4 mile, an area of 388 acres, and a maximum depth of 43.2 feet. These figures, particularly those indicating the maximum depth, are interesting because of the fabulous stories circulated as to the fathomless depths of this pretty little body of water. From the topographic relations and the thickness of the drift deposits penetrated by drills in the Baraboo basin to the north and in the Wisconsin Valley to the south, it is highly probable, however, that the rock bottom of the gorge in which the lake is situated lies fully 450 feet below the level of the water, buried beneath a great quantity of glacial débris. On the east, west, and south, bold bluffs of purplish quartzite rise from the water's edge to heights of 400 to 600 feet. (See Pl. VII, *B*.) At the north the entrance to the gorge is blocked by a ridge of morainal glacial drift; and east of Kirkland, where the curved gorge opens eastward, a second great ridge of morainal drift, rising 200 feet above the bottom of the valley, blocks the outlet. This lake is unique in that, though lying outside the limits of the glacial advance, it is yet retained by glacial dams at either end of the gorge. This was due to the peculiar topographic relations of the glacial margin, the great quartzite ridge, and the gorge, the last named having been excavated long prior to the incursion of the glaciers by a river, probably the ancestral Wisconsin River. The great ice sheet, advancing from the east, was retarded in its movement over the great rock ridge and did not traverse the crest west of Point Sauk, the highest point of the range 3½ miles east of the lake. On the lower slopes and in the valleys to the north and south, however, the ice pushed forward several miles farther. The side of the lobe thus formed in the Baraboo basin crowded into the north end of the gorge and formed there the north morainal dam.

On the south the ice crowded into the outlet of the gorge and up onto the end of the ridge to the south known as the Devils Nose. The débris brought forward and dropped in the gorge east of Kirkland formed the second morainal dam, thus inclosing the lake basin. Between the two ice fronts water was ponded to the height of the lowest col, which is above Messengers, near the east Sauk road—the road crossing the range just west of the lake. A. C. Trowbridge informed the writer that he found a crystalline bowlder, probably transported across the lake from the ice front by floating ice, 25 feet below this col or about 200 feet above the present lake. Sand, gravel, and finer silts washed into the basin from the two ice fronts completed the filling, except such small amount as has been washed into the lake from the surrounding slopes since the disappearance of the ice. (See also pp. 105–107 and 214–215.)

A feature which always excites wonder and speculation is the enormous quantity of great angular blocks of rock covering the steep slopes beneath the mural cliffs of quartzite which crown the bluffs. The popular belief is that these blocks have been thrown up from below during some great convulsion of nature, it being even supposed by some that the great gorge is the crater of an extinct volcano. So far as known, however, no igneous or volcanic rocks, except some crystalline bowlders that were brought by the glaciers, have been found within the gorge or on the neighboring bluffs. The rock in this part of the range is wholly quartzite, produced, as long ago demonstrated by Irving, by the close cementation of the grains in great beds of marine sands. The erosion of the gorge is the work of an ancient river and the great accumulation of angular blocks on its sides is the result of the tumbling down of fragments of the jointed quartzite detached by frost action, assisted perhaps by expansion and contraction due to changes of temperature, and by the disruptive action of tree roots. The continued falling of these blocks necessitates careful inspection of the railway at the foot of the east bluff to prevent accidents from the obstruction of the tracks.

MENDOTA, MONONA, WINGRA, WAUBESA, AND KEGONSA LAKES.

In the vicinity of Madison a chain of four beautiful lakes, Mendota, Monona, Waubesa, and Kegonsa, with a fifth and smaller one, Lake Wingra, lying at one side, extends northwest and southeast for about 15 miles. The outflow of the basins and of the adjacent marshes and slopes is carried off to Rock River by Yahara (Catfish) River. These lakes (see Pl. II, in pocket) lie in the line of a preglacial tributary of the ancestral Rock River valley. The basins, which owe their origin to inequalities in the surface of the drift that partly fills this valley, lie in the broader parts where the main valley was joined by lateral tributaries. These parts may also have been broadened and deepened still farther by the erosive action of the glacial ice which, during the last invasion at least, crossed the valley nearly at right angles, moving southwestward, or approximately parallel to the longer axes of the basins. The more constricted parts of the valley correspond to the intervals between the lakes.

Lake Mendota, the largest and most northerly of the lakes, has a length of 6 miles from east to west and a breadth of about 4½ miles from north to south. The hydrographic map issued by the Wisconsin Geological and Natural History Survey shows it to have an area of 15.2 square miles, a circumference of 21.9 miles, and a maximum depth of 84 feet. This depth is attained in a small pit in the bottom of the basin at a point about 100 rods southwest of Governors Island. The contours show a depth of 60 to 80 feet throughout a large part of the basin. At Maple Bluff, Farwell Point, and Governors Island on the northeast side of the lake, and at Eagle Heights on the south shore, and also on the north shore near Pheasant Branch, the waves are undercutting low bluffs of Cambrian sandstone. At Maple Bluff and Farwells Point the sandstone is capped by the Mendota limestone. Elsewhere the shores are of glacial drift where, in places, marshy tracts border the lake.

An interesting phenomenon developed on the shores of Lake Mendota and the other lakes is the presence in places of the ridges of earth and bowlders known as ice ramparts. The best development of this phenomenon observed by the writer was on the north shore of University Bay, at Picnic Point. The expansion of the modern lake ice under the processes of successive cracking and refreezing during periods of excessive cold caused it to crowd upon the shores of the somewhat constricted bay, and to push up the bowlders and earth into a ridge several feet in height and uproot and tip over some of the trees standing on the bank. The process was observed and described at one time of its marked development in 1899 by E. R. Buckley.[1]

Though the lake is deep, numerous wells drilled in the immediately surrounding area tend to show that the ancient valley in which it lies was much deeper. The rock bottom probably lies at least 300 feet beneath the surface of the water or more than 200 feet beneath the present bottom of the lake. One well drilled at Rocky Roost, a short distance off the shore of Governors Island, is reported by the driller, William Haak, to have penetrated drift for 140 feet without encountering the rock which outcrops on the shore of Governors Island, but a short distance away, and which at Farwells Point rises 80 feet above the lake level. Certain wells on the flat north of Middleton and between Middleton and the west end of the lake penetrate at least 200 feet of filling in a valley leading westward from this basin.

In his report on Wisconsin and Fox rivers, Gen. G. K. Warren[2] gives as his opinion that the drainage of the four lakes near Madison was formerly westward to Wisconsin River along the Black Earth Valley. He offers for the supposed change in direction of flow the same explanation that he predicated for reversal of flow in the Fox River valley, namely, elevation on the southwest with corresponding depression on the northeast.

As noted above, the evidence of well borings shows that the rock bottom of the basin lies far below the bottom of the lake, too far below to make it probable that the Black Earth Valley was ever low enough to have afforded an outlet for the basin. F. T. Thwaites is of the opinion that the channel underlies the lower part of the city between Capitol Hill on the east and the University Hill on the west, the axis lying a little east of the West Madison railway station. He traces a second buried channel around to the north and east of Elmside. The rock surface beneath the lower part of the city northeast of Capitol Hill, where the land is now low and marshy, and across which is the present outlet of Lake Mendota, varies from 20 to 140 feet below the surface, as shown by numerous drillings, but so far as is known to the writer there is no buried channel beneath this part with depth greater than this maximum.

R. D. Irving,[3] in his report on the geology of central Wisconsin, intimates that the basins of the four lakes were carved by glacial erosion.

N. M. Fenneman,[4] in his bulletin on the lakes of southeastern Wisconsin, discusses the partly filled ancient river valley in which the several lakes lie. He also suggests that the basin of Lake Mendota may have been deepened by the erosive action of the glacier so that its bottom may be lower than that of the preglacial stream valley. It is quite possible that the preglacial valley in the sandstone beneath Lake Mendota was deepened by glacial abrasion during the advance of the glaciers, and that there never was an outlet so low as the rock bottom indicated by the wells.

The surface of Lake Mendota is maintained about 5 feet above its natural level by a dam in the outlet in the northeastern part of the city of Madison.

The narrow neck of land between Mendota and Monona lakes, on which the city now stands, is composed of glacial drift varying in thickness from 20 to 140 feet. Lake Monona is smaller and somewhat shallower than its neighbor. Its dimensions, as stated on the hydrographic map, are: Area, 3.9 square miles; circumference, 13.2 miles; and greatest depth, 74 feet. The shores are bordered in places by marshes and are generally low, lying along drift ridges, except at one point on the east side and at Ethelwyn Park on the south side, where the waves are cutting into Mendota limestone. The lake is cut off from Lake Wingra and the surrounding marsh tracts on the west by a narrow glacial terminal moraine ridge.

Fenneman[5] gives the dimensions of Lakes Waubesa and Kegonsa, as determined by the hydrographic survey, as follows: Lake Waubesa, length 4.19 miles, width 1.40 miles, area 3.18 square miles or 2,035 acres, maximum depth 36.6 feet; Lake Kegonsa, length 3 miles, width 2.25 miles, area 5.38 square miles or 3,392 acres, greatest depth 31.4 feet. Some

[1] Buckley, E. R., Ice ramparts: Wisconsin Acad. Sci. Trans., vol. 13, pp. 142-162, 1901.

[2] Op. cit., pp. 271 and 272.

[3] Irving, R. D., Geology of central Wisconsin: Geology of Wisconsin, vol. 2, p. 613, 1876.

[4] Op. cit., 2d ed., pp. 39-43.

[5] Idem, p. 177.

broad marshy tracts border these lakes, but most of their shores consist of undulating drift areas. A low bluff of sandstone occurs on the west shore of Lake Kegonsa, and a hill of Lower Magnesian limestone rises near the water's edge on the northeast shore. The shores of all the four lakes are much frequented by summer cottagers.

ROCK AND RIPLEY LAKES.

In the western part of Jefferson County two small lakes—Rock Lake, on whose shore is the village of Lake Mills, and Ripley Lake, a mile east of the village of Cambridge—are very pretty bodies of water and are much frequented by summer residents. They lie in basins in a knobbed and pitted belt of morainal gravels that extends for more than 20 miles in a general north-south direction. The general relations, the evidence of neighboring wells, and the depths to which piling was driven in constructing the grade of the Chicago & North Western Railway across the extensive interlying marshes, indicate that the basins lie in the line of a buried preglacial valley. The depressions are believed to be due to the subsequent melting of great masses of ice which were buried in the morainal gravels with which the valley was filled.

LAKES OF THE OCONOMOWOC-PEWAUKEE DISTRICT.

Besides other natural attractions the northwestern part of Waukesha County includes, within an area measuring 14 miles from east to west and 9 miles from north to south, thirty or forty beautiful bodies of water ranging in size from ponds a few rods in diameter to Pewaukee Lake, 1 mile wide and 4½ miles in length. The geographic and topographic relations of these lakes are shown on the Oconomowoc topographic map of the United States Geological Survey. This is one of the most famous of the summer resort regions of Wisconsin, the shores of the lakes being dotted with hotels, beautiful summer homes of wealthy persons, and neat cottages of hundreds of less wealthy residents. The lakes have clean gravelly shores washed by clear cold spring waters and the surrounding country is varied by alternating knobbed and pitted morainal belts and flat gravel terraces, for this is a region which is traversed in a general north-south direction by the great Kettle interlobate moraine, from either side of which branch off marginal moraines bordered by flat outwash gravel terraces formed during the waning and recrudescence of the Green Bay and Lake Michigan glaciers.

These lakes (see Pls. I and II, in pocket) lie in a great reentrant in the margin of Niagara dolomite. The considerable depth to which the deeper wells penetrate the drift before reaching bedrock indicates that prior to the deposition of the drift a great valley or basin was scooped in the soft shale and dolomite. The conditions under which the glaciers melted in this region resulted in the burial of great irregular masses of ice in the morainal gravels and when later these masses melted away the gravels settled, leaving chains of depressions with their marginal slopes standing as steeply as the gravel would lie. The relations of each set of lakes to each particular moraine and terrace are described on pages 274, 278, and 281.

Most of the lakes drain through Oconomowoc and Bark rivers to Rock River. The levels of several of them are maintained by artificial dams. A few lie in inclosed basins without outlet.

Of the occurrence of marl in one of the lakes, Fenneman makes the following statement:[1]

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

Pewaukee Lake lies in a similar reentrant in the Niagara dolomite margin tributary to the larger valley on the west. The eastward recession of the front of the Lake Michigan glacier left the valley blocked on the west and on the east by morainal drift. Glacial striæ on the surface of the limestone exposed at Rocky Point and at the quarry near Pewaukee show that the direction of the ice advance was westward nearly parallel to the axes of the two parts of the lake basin and that the depressions in the rock may be, in part at least, the result of glacial erosion. The eastern half of the lake is

[1] Op. cit., 2d ed., p. 122.

very shallow, and the western half has a maximum depth of 45 feet.

Fenneman writes of this lake in part as follows:[1]

The level of the lake is now maintained by a dam at the outlet. This dam raised the lake 7 feet and is accountable for the eastern half of the lake, whose depth is for the most part less than 7 feet. Before the building of the dam, this half of the basin was a swamp, and a wagon road is said to have been maintained across the swamp, east of Rocky Point.

The two halves of the lake show scarcely less contrast in appearance than in history. Vegetation abounds on the bottom of the entire eastern half. Away from the shore it is kept from rising to the surface by annual mowing in the interests of the ice crop. Near the shores the vegetation encounters no opposition except from the waves and currents, whose strength has already been much reduced by friction on the bottom. Fields of bog, consisting of matted grasses, cover large areas. They rest loosely upon the bottom or are buoyed up by the water. They enlarge their areas by the annual growth at their edges, which appear as vertical faces going down to a bottom from 6 to 8 feet deep. In strong winds portions are dislodged from the field and become the so-called floating bogs.

The outflow goes eastward to the Fox and thence to Illinois River. A table, presented by Fenneman,[2] shows the dimensions of the several lakes in the Oconomowoc-Pewaukee district of which hydrographic surveys have been made.

Situation, area, and depth of lakes in the Oconomowoc-Pewaukee district (Tps. 7 and 8 N., Rs. 17 and 18 E.).

Name.	Elevation.[a]	Length.	Width.	Area.		Depth.	Remarks.
	Feet.	*Miles.*	*Miles.*	*Square miles.*	*Acres.*	*Feet.*	
Pewaukee	268	4.50	1.20	3.61	2,310	45.3	
Beaver	328	1.10	.44		148	47.6	East basin.
					163	46.2	West basin.
North	315	1.35	.75		328	78.0	East basin.
					126	73.6	West basin.
Pine	320	2.30	1.05	1.20	768	90.0	
Nagawicka	308	2.75	1.12	1.41	902	45.0	North end.
						94.5	Main lake.
Okauchee	299	2.37	1.80	1.72	1,000	65.0	Northeast bay.
						94.0	Main lake.
Garvin	299	.31	.19		20	36.1	
Mouse	304	.82	.21		91	66.3	
Oconomowoc	280	1.92	.82		645	62.6	South basin.
					174	49.2	
Upper Nashotah	290	.81	.40		137	51.2	
Lower Nashotah	288	.79	.25		99	46.2	
Upper Nemahbin	288	1.05	.56		273	62.0	
Lower Nemahbin	288	.93	.60		246	20.0	Northeast basin.
						29.0	Southwest basin.
						35.4	South basin.
Fowler	278	.94	.44		87	50.0	
Lac La Belle	271	2.70	1.12	1.84	1,178	33.0	Northwest basin.
						40.0	Southeast basin.
						46.6	Middle basin.
Silver	282	.97	.50		236	44.0	
Genesee, North	283	.51	.42		104	36.4	
Genesee, South	282	.40	.30		64	47.6	

[a] Above Lake Michigan, which is 579 feet above sea level.

PIKE, BIG CEDAR, ELKHART, AND OTHER LAKES.

In Washington County several beautiful little lakes including Pike, Big Cedar, and Elkhart, nestle among the ridges of the Kettel interlobate moraine and those of the bordering moraines. Of these Pike Lake lies 1½ miles southeast of Hartford. Big Cedar Lake, lying in a narrow elongated trough, extends 4 miles northward from a point 2 miles north of Schlesingerville. On either side of it abrupt morainal ridges rise 100 feet or more above the water level, and the soundings of the hydrographic survey show a maximum depth of 105 feet of water. The records of wells show that the ridges are composed wholly of glacial drift to depths equally as great. It thus appears that the basins of Big Cedar and of Silver and Little Cedar lakes to the east are wholly in drift. That they were left unfilled was probably due to the later melting of great masses of ice that had been buried in the gravels.

The troughs in whose bottoms the lake basins lie were doubtless occupied by streams of glacial waters flowing southward when the

[1] Op. cit., 2d ed., pp. 109-110.
[2] Idem, p. 175.

opposing fronts of the two glaciers were melted back a short distance from the interlobate morainal ridge.

In the southeastern part of Fond du Lac County several little lakes are scattered through the maze of kames and kettles and irregular marsh and swamp areas. Of these the largest is Long Lake, north of the village of Dundee.

In the town of Rhine, in the southwestern part of Sheboygan County, are several lakes of which Elkhart is the largest. This is a beautiful body of water, surrounded by wooded morainal hills and having an area, as determined by the Wisconsin Survey, of 304 acres and a maximum depth of 113 feet. While the basin itself is probably due to the melting of a great irregular mass of ice left buried by the glaciers, it is believed to be underlain by a considerable preglacial valley which extended southeastward and was occupied by the ancestral Sheboygan River. The upper part of this valley is now occupied by a great swamp nearly 20 square miles in extent, known as Sheboygan Swamp. The stream which drains this swamp flows over the buried rock rim of the ancient valley about a mile northwest of the village of Elkhart. Mr. Laun informed the writer that in drilling a well at Lakeside Park on the west shore of the lake unconsolidated material was penetrated to a depth of 240 feet without reaching the limestone bottom. The blocking of the valley was completed by the deposition of the sands and gravels of the interlobate moraine. The basin of Sheboygan Swamp was originally occupied by a lake of considerable size, but the cutting down of the outlet caused a lowering of the waters; and the growth of vegetation and its accumulation to considerable depths in the basin has changed the lake into a swamp largely overgrown with tamarack.

LAKE BEULAH AND LAUDERDALE LAKES.

In the southern part of Waukesha County and the northern part of Walworth County, in the region of Mukwonago and East Troy, are several small lakes, among these Lake Beulah and the Lauderdale lakes, which are popular as summer resorts. The whole series of lakes in this district lies in the line of a great buried valley which, in preglacial time was cut far back into the margin of the Niagara dolomite and downward through the underlying shale into the Galena dolomite. (See Pls. I and II, in pocket.) Wells in the vicinity show that the bottom of this valley lies far beneath the bottoms of the little basins in which the lakelets lie. The characters of the basins, which are irregular pits or chains of pits in an extensive pitted gravel plain, show them to have resulted from the melting of great ice blocks which were buried when the thinned margin of the Lake Michigan glacier, melting backward toward the east, was buried in a great deposit of gravels laid down by waters escaping from this and the Green Bay Glacier. In the accompanying table are the dimensions of the lakes as cited by Fenneman.[1]

Dimensions of lakes in the Mukwonago-East Troy region.

Lakes.	T. N.	R. E.	Length.	Width.	Area.	Depth.	Remarks.
			Miles.	*Miles.*	*Acres.*	*Feet.*	
Lauderdale: Green	4	16	1.09	0.66	282	56.8	
Middle	4	16	1.60	.45	282	50.0	
Mill	4	16	.75	.49	a 304	50.0	
Beulah: Mill	4	18			61	51.5	
						40.0	Southeast basin.
Lower	4	18	2.65	1.10	550	55.5	Southwest basin.
						46.5	Northeast basin.
Round	4	18			100	40.0	
Upper	4	18			260	67.0	
Booth	4	18	.58	.43	125	25.4	
East Troy	4	18	.50	.39	81	16.5	

a Including large marshy extension.

GENEVA, COMO, AND DELAVAN LAKES.

Lakes Geneva and Delavan, in southern Walworth County, are among the most beauti-

[1] Op. cit., 2d ed., p. 177.

ful and popular of Wisconsin's many lakes. They lie just within the great terminal moraine of the Delavan lobe of the Lake Michigan glacier, where the ice spread out across what is believed to be a great buried valley, the preglacial Troy Valley, and left its marginal moraine deposited in a great arc. Much of the several hundred feet of glacial drift beneath which the valley is now buried was undoubtedly deposited by the glaciers of the pre-Wisconsin and early Wisconsin stages, but the lake basins are the result of depressions in the drift surface as left behind the moraine by the melting of the last ice sheet.

Lake Geneva lies in a buried valley tributary to the main trough. A well drilled at Yerkes Observatory near Williams Bay penetrated 400 feet of drift piled in successive sheets on the slope of this ancient valley, and it is probable that the thickness of the drift opposite the west end of the lake is considerably greater. The dimensions of Lake Geneva as given by Fenneman[1] are, length 7.5 miles, width 2 miles, area 8.6 square miles, and maximum depth 142 feet. The greatest depth is in the western part, between Camp Collie and Cooks Camp. The bottom of the basin thus lies about 280 feet below the lowest part of the crest of the moraine which retains it on the west and 300 to 400 feet below the tops of the ridges on the north and south. The lake shallows toward its east end, where there is an outlet by way of White River to Fox River at Burlington. The dimensions of Delavan Lake, as given by Fenneman,[1] are, length 3.75 miles, width 1.1 miles, area 2.7 square miles, and greatest depth 56.7 feet. Artificial dams maintain the water levels of both Geneva and Delavan lakes.

Lake Como is a small lake lying between the drift-mantled slopes of a valley a short distance north of Lake Geneva.

TISHIGAN, BROWNS, POWERS, TWIN, SILVER, CAMP, AND OTHER LAKES.

Nestling among the gravel hills of the morainal belts bordering Fox River in the western parts of Racine and Kenosha counties are a dozen or more small lakes (Tishigan, Browns, Powers, Twin, Silver, Camp, and others), each a favorite with a host of summer visitors. These occupy ice-block depressions in the glacial gravels with axes 1 or 2 miles or less in length.

[1] Op. cit., 2d ed., p. 177.

MUSKEGON AND WIND LAKES.

Wind Lake, in Racine County, and the Muskegon lakes, in Waukesha County, which are the haunts of sportsmen, occupy parts of a great marsh tract which was once the site of a much larger body of water, but which has since been overgrown with peat-forming vegetation and has been drained.

MARSHES AND SWAMPS.

It is difficult to compute the actual area of wet lands within the bounds of the district under discussion, but a glance at the map (Pl. III, in pocket) shows it to be hundreds and perhaps thousands of square miles. A large part of this poorly drained land is scattered among the drift hills and ridges in small tracts, but much of it lies in basins of large acreage. Notable among these basins is that of Sheboygan Swamp in northwestern Sheboygan County, which extends over an area of something like 20 square miles, not including adjacent nearly connected tracts. Horicon Marsh, in northeastern Dodge County, has a length of 13 and a width of 5 miles. Its site, like that of Sheboygan Swamp, was originally occupied by a lake, which was held in the shallow basin by the morainal deposit on which is built the city of Horicon. The outflow cut a channel through the obstruction and drained the lake. After the country was settled by the whites the construction of an artificial dam restored the lake for a time, but with the later removal of the dam the lake again gave place to the marsh. Efforts said to have been made to drain Sheboygan Swamp in order to utilize a deposit of marl said to underlie the peat were stopped by the discovery that the stream flowing out of the basin crossed the rock rim of the ancient valley, which made ditching difficult. No special study of the peat, marl, or other contents of the swamps and marshes was made by the writer during the present investigation. It seems probable, however, that valuable deposits may occur in many of the basins and that in time their utilization will be found profitable. Vast quantities of hay are now cut annually from these wet lands, and certain grasses cut in places from the marshes along Fox River are used in the manufacture of matting. Owing to the obstruction of the ancient drainage lines by drift deposits and the shifting of the streams in many places to new courses, where excavation was retarded by rock sills, very little has been accomplished toward the natural drainage of the wet lands. Many tracts have been partly reclaimed by artificial drainage, but it will be difficult, if not impossible, to drain them completely. Many of the tracts were undoubtedly occupied by lakes after the melting of the glaciers uncovered the uneven surface of the drift and some of these were partly drained by the erosion of outlet channels. Vegetation has also done much toward the reclamation of the areas and may eventually accomplish more by filling up the basins than artificial or natural outlets can do by draining them.

Chapter III.—GEOLOGIC FORMATIONS UNDERLYING THE GLACIAL DRIFT.

DISTRIBUTION AND SEQUENCE OF THE ROCKS.

It is necessary for the understanding of the work of the Pleistocene glaciers to know something of the character and distribution of the underlying rock formations. The preglacial topography, or the configuration of the land before the advent of the glaciers, was very largely dependent on the streams, the work of which in turn depended very largely on the structure, composition, attitude, and distribution of the several rock formations, now very largely concealed by drift. The deployment of the glaciers was in large measure controlled, or at least influenced, by the configuration of the land traversed. Moreover, the larger part of the material composing the drift in this area was derived from local rock formations, so that the character and structure and composition of the various forms of glacial deposits were determined to a great extent by the distribution and lithologic character of the several underlying formations.

Although the older rocks are largely concealed by the drift, many small exposures show their character and attitude, and the collection and correlating of the records of thousands of well borings have enabled the distribution of the several formations to be approximated throughout the area. (See Pl. I, in pocket.) It is to be understood that in those parts where the margins of the formations are buried from view the boundaries shown are only approximate. In this mapping the maps and reports of the Wisconsin Geological Survey, prepared under the direction of T. C. Chamberlin, when State geologist, as also those of the later Wisconsin Survey, have been of great assistance and have in general been followed. Changes in the location of boundaries have been made only where there was positive evidence, or at least very strong presumption, of error. Most of them are in places where the covering of drift is thick and where well borings have shown that the formations immediately underlying the drift were other than those shown by the older maps.

It is not proposed to go into an exhaustive discussion of the pre-Pleistocene geology, to consider fully the fossil faunas which are in some cases so finely developed, to treat exhaustively the chemical and microscopic characters of the igneous and metamorphic rocks, or to discuss fully the correlation of these various formations with others in this or other States. The nomenclature followed is principally that in use by the Wisconsin Geological and Natural History Survey.

The north-central part of Wisconsin is underlain by a series of igneous and metamorphic rocks of Archean and Algonkian age. This area, which ranges in general elevation between 1,000 and 2,000 feet above the sea, comprised one of the oldest nuclei about which the sediments composing the successive formations underlying the North American continent were laid down in marine waters. The rock structures show that the region was at one time mountainous but that even before the deposition of the Paleozoic sediments it had been reduced by erosion to a peneplain with a few remnants of higher levels rising as isolated rock hills. During the successive incursions of marine waters over the continental interior sediments were deposited, surrounding and burying these ancient hills and ridges and lapping about the nuclear land area, from which they dip radially in all directions from southeast to southwest. The formations in the southeastern quarter of the State thus range in age from probable Archean to Devonian, but none later than the Archean now have their original extension. Erosion during the long interval between the final emergence of the area from beneath the sea and the incursion of the first great glacier cut away hundreds of feet of rock whose material was borne away by the streams for deposition in surrounding areas. In a general way it may be said that the several formations are beveled off—that is, their marginal parts have been thinned by erosion after rising successively to the surface of the general plain. Owing to the alternation, however, of harder limestone formations with softer sandstones and shale the exposed margin of each of the limestones is marked in places by a more or less well-defined line of bluffs or cuestas facing north and west, beyond which lie lower tracts from which the softer rocks have been very largely removed. The belts of outcrop of the several formations have thus a general north or northeast trend through the area under discussion. The belts of the lower rocks swing around to the west in the southwestern part of the area and beyond this curve again to the northwest. The succession of formations is shown in the table below, the youngest and uppermost being cited first and the oldest last.

Geologic formations underlying the glacial drift of eastern Wisconsin.

	Feet.
Tertiary (?) gravels.	
Devonian:	
Milwaukee formation (Hamilton of early Wisconsin reports). Impure bluish magnesian limestone, highly fossiliferous, used for manufacture of cement. Associated with this but now buried beneath the drift near the lake shore are beds of blue and black shale. Maximum thickness	122
Unconformity.	
Silurian:	
Waubakee dolomite (Lower Helderberg of early Wisconsin reports). Thin-bedded grayish dolomite, very few fossils	2–30
Unconformity.	
Niagara dolomite. Largely heavy-bedded white to grayish dolomite, with layers of chert nodules at certain horizons; generally fossiliferous	120–719
Unconformity.	
"Clinton" iron ore, and perhaps red ocherous limestone in southeastern counties	10–28
Unconformity.	
Ordovician:	
Maquoketa shale (Cincinnati shale of early Wisconsin reports). Bluish and greenish clay shale, with a few intercalated thin layers of magnesian limestone; highly fossiliferous in part	40–365
Galena dolomite. Buff to grayish rather heavy bedded dolomite, of porous and uneven texture, especially in the southern part of the area, with abundant chert nodules at certain horizons; highly fossiliferous in places	25–225
Ordovician—Continued.	
Trenton limestone.[1] Buff to bluish and grayish magnesian limestone, partly thin bedded and shaly, highly fossiliferous in part; thickness about 125 feet. Combined thickness of Galena and Trenton	150–350
St. Peter sandstone. Light-colored buff to reddish friable sandstone, varying greatly in thickness; nonfossiliferous. In places only a few inches thick; maximum thickness	200
Unconformity.	
Lower Magnesian limestone.[1] Mostly heavy-bedded rough-textured porous magnesian limestone, with much disseminated white and colored chert. Fossils very rare or absent. Locally there is at the top a little whitish and purplish shale which grades into red sandstone. Owing to the irregularity of its upper surface it varies greatly in thickness and in places wedges out; maximum thickness	250
Cambrian (Potsdam sandstone of Wisconsin reports):	
Madison sandstone.[2] Light-colored friable sandstone. Fossils rare or absent.	30–50
Unconformity (?).	
Mendota limestone:[2]	
(1) Buff and purplish magnesian limestone, partly heavy bedded, partly thin bedded and shaly; partly fossiliferous	10–30
Unconformity (?).	
(2) Sandstone[3] (not everywhere present in the section).	
(3) Thin-bedded buff and purplish magnesian limestone and calcareous sandstone, with some greensand[3]	10–30
Main body of Cambrian sandstone, consisting of light-colored, friable quartz sandstone with some included layers of red shale. Becomes coarse in the lower part and near the contact with knobs and ridges of pre-Cambrian rock (as near the Baraboo and Waterloo quartzites and the rhyolite at Berlin and Observatory Hill) becomes a massive basal conglomerate of rounded pebbles and bowlders in a sandstone matrix	775

[1] Owing to the fact that the increase in knowledge of the rocks of this part of the Paleozoic section in southeastern Wisconsin since the publication of the early Wisconsin Survey classification has been slight, the name applied by that Survey is used in this report.

[2] This name is used in the sense in which it is used by the Wisconsin State Survey. Both the Madison sandstone and Mendota limestone are considered post-Cambrian by E. O. Ulrich and C. D. Walcott.

[3] Nos. 2 and 3 have generally been regarded as Madison and Mendota, respectively, where not overlain by No. 1, but are differentiated by Ulrich (personal communication, December, 1914), and regarded by him as (2) Jordan sandstone and (3) St. Lawrence formation.

	Feet.
Cambrian—Continued.	
Maximum known thickness of all Cambrian	965
Great unconformity, due to upturning and erosion.	
Algonkian:	
Huronian series:	
Upper Huronian (?) quartzite in Baraboo basin. (Not exposed at surface)	50
Unconformity.	
Granite intrusive in lower formations. (Slightly exposed in south slope of Baraboo range and near Portland. Not shown on map.)	
Middle Huronian (?):	
Freedom dolomite. Principally dolomite, with slate, chert, and iron ore and all gradational phases of these rocks. Known only in Baraboo basin. Not exposed at the surface	950±
Seeley slate. Soft gray slaty rock, known only in Baraboo basin; not exposed at the surface	500–1,000
Baraboo quartzite. Pink to purplish red quartzite with a little schist due to shearing along bedding planes. Basal conglomerate with rhyolite pebbles in a quartzite matrix exposed at one point near Alloa	4,000–5,000
Waterloo quartzite. (Separate area. Relations to Baraboo quartzite not certainly known.) Bluish, purplish, pink, and white quartzite with veins of intruded pegmatite.	
Unconformity due to erosion.	
Archean:	
Rhyolite, granite, and diorite, exposed at several points outside the Baraboo quartzite range and encountered in some wells beneath the Cambrian sandstone.	
Isolated knobs surrounded by Paleozoic rocks. Mutual age and stratigraphic relations unknown.	
Granite (alkali granite) in Seneca Township.	
Granite (alkali granite) at Montello.	
Rhyolite (soda aporhyolite) at Berlin.	
Rhyolite (soda aporhyolite) with diabase dikes near Marquette.	
Rhyolite (soda aporhyolite) at Utley.	
Rhyolite (soda aporhyolite) near Endeavor.	
Rhyolite porphyry (soda aporhyolite porphyry) of Observatory Hill.	
Rhyolite (soda aporhyolite) in Marcellon Township.	

Except for the small outcrops of granite and diorite on the south side of the south range of Baraboo quartzite and except for the Freedom dolomite, the Seeley slate, and the upper Huronian (?) quartzite, which are not exposed at the surface and have only been discovered in prospecting for and mining of the iron ore in the trough inclosed by the Baraboo quartzite ranges, all of the several formations have had an influence on topographic and glacial conditions or have made contributions to the glacial drift which are to be distinguished from drift of more distant derivation. The general geologic character and topographic expression of the several formations will therefore be given consideration.

PRE-CAMBRIAN FORMATIONS.

ARCHEAN CRYSTALLINE ROCKS.

General relations.—With the exception of the outcrops of rhyolite which occur on or near the outer slopes of the Baraboo ranges and near the base of the quartzite the exposures of pre-Cambrian crystallines occur as isolated ledges or knobs surrounded by Paleozoic sedimentaries. They are the crests of monadnocks which once rose above the pre-Cambrian peneplain. These were buried in Paleozoic sediments deposited during the successive marine submergences of the region and were only rediscovered when pre-Pleistocene erosion had removed the enveloping sedimentaries down to the Cambrian sandstone or the Lower Magnesian limestone. Most of them thus occur in the northwestern part of the area where the Cambrian sandstone underlies the drift. Many of the ledges yielded fragments to the overriding glaciers, and bowlders from the disintegrated Cambrian basal conglomerates were picked up and carried westward and left in the lee of the ledges when the ice melted. Evidence from the boring of wells at several places shows that other pre-Cambrian monadnocks of igneous rock still lie buried beneath the Paleozoic rocks in those parts of the area where erosion had not progressed so far. As these, however, were not exposed to abrasion by the Pleistocene glaciers they will not be considered in this connection.

Granite (alkali granite) in Seneca Township.—Beginning at the most northwesterly exposure in the SE. ¼ sec. 2, T. 17 N., R. 11 E. (Seneca Township, Green Lake County), Pine Bluff, a rounded or elliptical knob of rather coarse grained gray to pinkish alkali granite rises about 120 feet above the broad marshes on the west which are drained to Fox River by White River. This knob, which has a length of about 80 rods and a width of 40 rods is only about 2 miles distant from the granite ledges of southern Waushara County, just north of the limits of the area under discussion. No sedimentary rocks are exposed in the neighborhood, but the Cambrian sandstone probably underlies the drift. The rock, which was described by R. D. Irving[1] as a quartz porphyry, has a rather fine grained matrix made up largely of glassy feldspar crystals with scattered larger crystals of similar character. Other parts have more evenly crystalline granitic texture. The rock in places has a pinkish tint. Weathered parts in places show a buff to brownish kaolinized surficial zone about one-half inch thick, below which the pinkish tint grades downward into the gray. It is not certain that this represents the depth of postglacial weathering. It may be only the remains of a much thicker zone of preglacial decomposition which was not entirely removed by glacial abrasion. No abrupt ledges are seen, the surface being smoothly rounded and striated with glacial scratches trending N. 60°–73° W.

Rhyolite (soda aporhyolite) at Berlin.—About 7 miles east of Pine Bluff, in the eastern part of the city of Berlin, is an elongated ledge of rhyolite (soda aporhyolite) nearly three-fourths mile in extent from east to west and 80 to 100 rods in width. This lies at the west end of a low ridge and rises about 150 to 200 feet above Fox River, which is about three-fourths mile distant on the northwest. The rock, which is well exposed in the quarries of the Wisconsin Granite Co. to depths of 20 to nearly 100 feet, is massive but broken by a large number of joints. The main joints are nearly vertical or highly inclined, but others lying nearly horizontal or dipping at low angles or curving in low flat domes cut the rock into large angular blocks. The rock is nearly uniform in color and texture, a dense dark bluish gray, which varies in places to a pinkish gray where the larger feldspar crystals are more abundant. The rock has a well-marked nearly vertical cleavage along which it splits readily under the hammer, but it breaks less regularly and less easily in other directions. On this account and on account of the numerous joint cracks, bowlders derived from this ledge are apt to be elongated and angular rather than rounded. Along some of the joints, especially those where shearing has occurred, considerable weathering has taken place. Here the material is softer and varies in color from purplish to light greenish and pinkish ashen-gray, with joint faces of rusty reddish-brown. D. E. Brewer, well driller, informed the writer that in making one of John Kobb's wells, a few rods north of the eastern part of the ledge, the drill penetrated 2 or 3 feet of reddish material ("soft iron") between the "granite" and the overlying sandstone. He also encountered a layer of "mud" in Mr. Witte's well a few rods farther east at the same horizon. This may have been derived from the igneous rock by weathering in pre-Cambrian times, or it may be reddish shale of the Mendota horizon. If exposed to glacial abrasion it would yield reddish material to the drift.

At the upper northwest side of the middle quarry, at the west end of the ridge, 15 to 20 feet of conglomerate overlies the rhyolite ledge. This consists of large and small subrounded bowlders, some of them 6 feet in length, with interspersed smaller angular and rounded fragments of rhyolite and a sandstone matrix. A little of the same conglomerate is also exposed at the east end of the ledge. Sandstone and conglomerate have also been seen along the south slope of the ridge. Chamberlin[2] reports that F. H. King collected from these beds several species of Cambrian fossils, among which were the trilobites *Conocephalites* and *Dikellocephalus*, showing the sandstone to be of Cambrian age. These relations show clearly that the knob of crystalline rock was not due to post-Cambrian igneous intrusion, but that it stood as an island in the Cambrian sea at the time of the deposition of the sandstone, the pebbles and bowlders of rhyolite being worn and rounded by the dashing of the waves against the ledge. From relations of the rock exposures, the records of well borings furnished by D. E. Brewer, and data given by Weidman,[3] it appears that the exposed ledge is the top of an isolated monadnock which stood above the pre-Cambrian peneplain with a relief of 600 or 700 feet or more. The exposure of the crest of

[1] Geology of Wisconsin, vol. 1, p. 520, 1883.

[2] Geology of Wisconsin, vol. 2, p. 267, 1877.

[3] Weidman, Samuel, A contribution to the geology of the pre-Cambrian igneous rocks of the Fox River valley, Wis.: Wisconsin Geol. and Nat. Hist. Survey Bull. 3, p. 33, 1898.

this hill and of the enveloping conglomerate by preglacial erosion permitted the derivation of considerably decomposed pebbles and bowlders of rhyolite by the glaciers from the conglomerate and possibly also of fresher blocks from the ledge itself. That some of the enveloping sandstone and conglomerate yet remains after several glacial incursions, however, indicates that the amount of glacial abrasion of the ledge itself was very moderate.

Rhyolite (*soda aporhyolite*) *at Utley*.—Seventeen miles nearly due south of Berlin and 5 miles northeast of Markesan, in the N. ½ sec. 36, T. 15 N., R. 13 E. (Green Lake Township), a single elliptical knob of rhyolite (soda aporhyolite) about 80 rods long and 40 rods wide stands in the midst of the small valley of Grand River. The smoothly rounded crest of this knob, whose major axis trends about S. 50° W., rises about 100 feet above the marshy flat north of the railway along the must have facilitated the removal of blocks by the plucking action of the overriding ice.

No exposures of conglomerate were noted on the slopes of this ledge; in fact, no sedimentaries have been observed in contact with the rhyolite except a patch of limestone thought to be Trenton, observed by Weidman[1] on the eastern slope near the summit. There can be no doubt, however, that the knob is another of the pre-Cambrian monadnocks whose flanks were washed by the waters of the early Paleozoic seas. Its crest (see fig. 1) rises clear through the zone of the Lower Magnesian limestone and the St. Peter sandstone into that of the Trenton limestone. It is, therefore, a safe inference that the pre-Cambrian monadnock formed by this knob was originally higher than that at Berlin, unless, indeed, the original top of the Berlin knob was removed by glacial and preglacial erosion. Standing, as it does, in the midst of

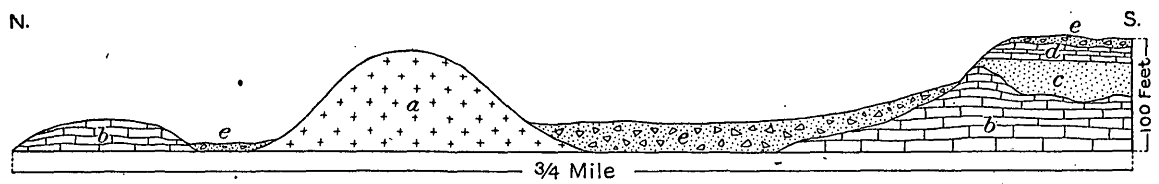


FIGURE 1.—Diagrammatic section showing the relations of the aporhyolite ledge at Utley to the surrounding formations: *a*, Pre-Cambrian aporhyolite; *b*, Lower Magnesian limestone; *c*, St. Peter sandstone; *d*, Trenton limestone; *e*, glacial drift.

stream. The rock has a dense very dark (almost black) purple or grayish-purple matrix, through which are scattered small, glassy, and pinkish quartz and feldspar crystals one-sixteenth to one thirty-second inch in length. In places these crystals are somewhat larger and more closely set, and the matrix takes on a reddish tint. The rhyolite is very hard and brittle and, unlike the rhyolite at Berlin, has no definite cleavage. It is a massive rock and is cut by many joints, most of whose walls are rusted brownish. Many of these joints have smooth flat faces and cut the mass into great angular blocks whose dimensions vary from a few to 10 feet. Earlier-formed joints have been recemented by quartz vein filling. Exfoliation by cracks curving nearly parallel to the curving surface of the knob has loosened blocks and slabs varying in thickness from a few inches to 5 feet. Some of this exfoliation has taken place since the glaciers smoothed the rounded surface of the knob. Such action prior to the invasion of the ice a valley about 100 feet in depth cut in the margin of the upland, the knob must have been subjected to vigorous action by the concentrated basal flow of the ice and should have been well eroded if rock-shod glacial ice is competent to such action. It should be remembered, however, that though any conglomerate which may have been present has at some time been removed, the rock of the ledge is very hard and could, for the most part, have been carried away only where it had been previously loosened by jointing and frost action. The ice of the last glacier crossing this region moved about S. 60° W., so that bowlders derived from this ledge should be found scattered in the drift to the west and southwest. Practically no disintegration of the rock has taken place since the last glaciation. A large part of this ledge has been removed by quarrying.

Rhyolite (*soda aporhyolite*) *near Marquette*.—Between 12 and 14 miles west of the Utley

[1] Weidman, Samuel, Wisconsin Geol. Nat. Hist. Survey Bull. 3, p. 5.

ledge, near the south shore of Lake Puckaway, a mile southwest of the village of Marquette, in secs. 34 and 35, T. 15 N., R. 11 E., and secs. 1 and 2, T. 14 N., R. 11 E. (Marquette township), is a group of knobs of rhyolite (soda aporhyolite) not greatly different from the Utley rock. They rise abruptly 50 to 150 feet above the surrounding sandy and marshy plain. Considerable drift is banked about the east sides of some of them, but a large part of the rock surface is bare or thinly covered with soil and trees. The mass of the rhyolite is dark reddish-purple or dark purplish on the fresh surface and dull reddish or grayish-red on the weathered surface. In the quarry ledge at the northwest side of the group the rock is mainly porphyritic, white and pinkish feldspar phenocrysts, mostly less than one-sixteenth inch in diameter, being scattered through the dense dark groundmass. Noble's quarry exposes the rock to a width and depth of 50 to 60 feet. The massive rhyolite is not marked by any banded structure at this place but is cut into polygonal blocks a few inches to 8 feet in diameter by nearly vertical or highly inclined and by low-lying joint planes. Southeast of the quarry, as shown by Hobbs and Pretts,[1] the rock becomes largely felsitic. In some of the knobs there are small rounded spherulites. A grayish banding, in places contorted by flow structure, characterizes the volcanic rock in several places; and the breaking up of hardened layers before the flow had entirely ceased resulted in a finely developed rhyolite breccia (Pl. VII, *A*, p. 40) composed of angular fragments of the dark-banded and contorted rhyolite in an ashen-gray matrix. The banded rhyolite and the rhyolite breccia are rocks of striking appearance and may be readily identified at many points in the drift to the west. A few northeast-southwest dikes of dense dark-gray diabase cut the rock.

No conglomerate is known to occur about the slopes of the ledges. If such was present when the glaciers invaded the region, it would have yielded rounded bowlders, but most of the blocks derived from the ledges are angular, probably having been loosened by jointing and frost action. The rock is hard and brittle, and practically no disintegration has taken place since the last glaciation. The surfaces of the ledges are smoothly rounded (Pl. XXI, *B*, p. 204) and striated with, in places, a fine development of the crescentic markings known as chatter marks. The general direction of the ice movement over the ledges was nearly due west, but divergence of the basal currents about the rounded crests give striæ ranging from N. 57°-86° W.

A well driller stated that none of the wells at the neighboring farm houses, off the slopes of the ledges themselves, reach the crystalline rock, the only rock encountered below the drift being sandstone or limestone, which is of Cambrian age. Here again, then, is another of the pre-Cambrian monadnocks. The crest of the knob near the quarry has an elevation of about 960 feet above sea level, according to the mapping of Hobbs and Pretts. This is about 200 feet above the level of Lake Puckaway. Three miles northwest of this ledge at the Chicago or Nee-Pee-Nauk clubhouse, on the north shore of the lake, D. E. Brewer, Berlin, drilled a well to a depth of 330 feet in unconsolidated sand and clay. The crest of the knob thus stood over 500 feet above the bottom of the preglacial valley on the north and in pre-Cambrian time its relief was probably greater than this.

Granite (alkali granite) at Montello.—Seven or eight miles northwest of the Marquette ledges, in the eastern part of the city of Montello, a ridge of alkali granite mantled with glacial drift rises 80 or 90 feet above Fox River on the south. The quarry of the Montello Granite Co. at the west end of the ridge gives an excellent exposure of the structure of the ledge to a depth of 80 to 90 feet or more. The rock, which is used for monumental work, coursing stone, paving blocks, and crushed stone, is a medium-grained granite of reddish to grayish-red color, and is of uniform texture. It is cut into large polygonal masses by numerous joints trending in various directions and mostly inclined at high angles so that blocks 5 by 8 feet and 6 by 7 feet in size may be removed. In addition to the open joints the rock contains many incipient cracks, which become visible only after the rock has been taken out and wet down. These facilitate breaking and by permitting infiltration of moisture must have aided the frost to loosen

[1] Hobbs, W. H., and Leith, C. K., The pre-Cambrian volcanic and intrusive rocks of the Fox River valley, Wis.: Wisconsin Univ. Bull. 158, vol. 3, p. 258, 1907.

blocks for removal by glacial action. The rock is cut by several dikes of dense, dark-greenish, fine-grained diabase branching in places and varying in thickness from a few inches to 4 or 5 feet. Some shearing has taken place along nearly vertical joints, developing schistosity. In one place there is a downthrow of 6 inches along a joint trending N. 50° E. and dipping 55°. The removal of 6 to 8 feet of sandy till and an underlying 5-foot bed of stratified sand and gravel at the former site of the Catholic Church above the Montello Granite Co.'s quarry shows the surface of the granite ledge to be smoothly rounded and striated by ice moving N. 77°–87° W. Chatter marks are also finely developed in places. The vertical face of one ledge 6 feet in height and trending S. 60° W. is striated nearly horizontally, showing the adaptation of the basal flow of the ice to the inequalities of its bed. The same rock is also exposed in J. C. Merkle's quarry in the south slope of the ridge below the high school, and again at a point on the ridge about a mile east of the main quarry. At the latter place the granite is sliced by closely parallel joints trending N. 30° E. and dipping 72° NE. The surface of the rock here is very uneven, possibly as the result of glacial plucking, and the tops of the projecting points are rounded by glacial abrasion. At the natural exposures the surface of the granite is weathered grayish-white but is hard and undecomposed.

No sedimentary rocks are exposed in contact with the granite or in the immediate vicinity, so far as noted by the writer. Ben Neck, well driller, informed the writer, however, that a well near the corner of Clay and Cass streets on the ridge east of the high school penetrated 50 feet of glacial drift and 6 feet of sandstone (Cambrian) containing boulders. From this it appears that the surface of the granite declines rapidly eastward and is mantled by Cambrian basal conglomerate. Other wells cited by Mr. Neck show the abruptness of the preglacial slope and of the pre-Cambrian monadnock. A well at the machine shop north of Quarry Street opposite the quarry and about 50 feet lower than the crest of the ledge penetrated 90 feet of drift. The artesian well one block west of the quarry penetrated drift to a depth of 90 feet or to a level about 170 feet lower than the crest of the ledge. At the corner of Barstow and Main streets, opposite the south side of the ledge, rock was encountered in digging a store cellar, but at the second store south of the corner it underlay 60 feet of drift. At the courthouse, a short distance to the south, 80 feet of drift was penetrated; and at Christ Tagatz's on Main Street, south of Lake Street, about 80 rods south of the ledge, an artesian well 160 feet deep did not reach rock. Fox River flows only a short distance south of the ledge, and as the well drilled at the Chicago club house on the north shore of Lake Puckaway, 6 miles east of Montello, showed the preglacial valley to have a depth of at least 330 feet, it is probable that the preglacial relief of the Montello ledge was more than 400 feet on the south.

Rhyolite (soda aporhyolite porphyry) of Observatory Hill.—Between 5 and 6 miles south of Montello, in the SW. ¼ sec. 8, T. 14 N., R. 10 E. (Buffalo Township), Observatory Hill rises abruptly about 250 feet above the surrounding area. The core of this knob is dense, nearly black soda aporhyolite porphyry, speckled with pink and glassy phenocrysts of feldspar and quartz.[1] On the flanks of the knob sandstone occurs with conglomerate in places to heights of 100 to 150 feet. Very numerous joints trending at various angles cut the rock into angular blocks such as would facilitate glacial plucking. The surface is thus rather uneven, but the rounded and smoothed projecting angles of the upper southeast slope show the effects of glacial abrasion. Striæ noted in several places, particularly on the smoothly rounded surface, trend N. 45°–74° W. The northwesterly trend is probably the result of shifting of the basal flow of the ice about the north side of the knob by the projection of a long spur southeastward from the crest of the knob. West-sloping surfaces show the effects of etching by the sand blown up from the surrounding sandy plain. The weathered surface of the rock varies in color from purplish to reddish and grayish. The rock is firm and hard, with no surficial layer of decomposed material. The crest of this knob has an elevation of 1,100 feet above sea level, or about 40 feet above the base of the Lower Magnesian limestone at its nearest occurrence about 6 miles to the southeast.

Rhyolite (soda aporhyolite) near Observatory Hill.—About 1½ miles southeast of Observatory Hill, beyond an intervening hill of sandstone, is a low rounded ledge of the same rock on the

[1] Hobbs, W. H., and Leith, C. K., op. cit., fig. 4, p. 256.

D. Taylor estate, in the NE. ¼ sec. 13, T. 14 N., R. 10 E. (Buffalo Township). The surface is crosscut by joints and marked with glacial striæ trending N. 60°–83° W. At one point curving striæ were noted which shifted gradually from N. 67° W. to N. 83° W.

Rhyolite (soda aporhyolite) near Endeavor.—About 5 miles west of Observatory Hill, near the west bank of Fox River, east of the village of Endeavor, in secs. 5 and 8, T. 14 N., R. 9 E. (Moundville Township), is a group of ledges of soda aporhyolite similar to that of Observatory Hill. The rock has a dense matrix and is dark purplish in color (somewhat lighter on the worn and weathered surfaces). Through the matrix are sprinkled small pinkish and glassy phenocrysts of feldspar and quartz. In places the rock contains sufficient magnetite in disseminated fine particles slightly to deflect the needle of a compass held against its surface. The ledges are low, 10 to 20 feet in height. Their surfaces are generally rounded but in places are uneven as the result of glacial plucking of blocks from between the numerous joint cracks whose angles are rounded by the abrasive action of the rock-shod ice. At one point what appeared to be faint glacial striæ trending N. 58° W. were noted. No sedimentary rock is exposed in the immediate vicinity, but the ledges are in the area of the Cambrian sandstone.

Rhyolite (soda aporhyolite) in Marcellon Township.—Between 5 and 6 miles south of Observatory Hill and about 7 miles northeast of Portage, in secs. 7, 8, 17, and 18, T. 13 N., R. 10 E. (Marcellon Township), a group of ledges of soda aporhyolite rise 50 to 70 feet above the surrounding surface. The larger ledge east of the road occurs at the west end of a large drift-covered hill 160 feet or more in height, so that the extent of the rock in that direction is not known. The well at Elmo Morgan's house, between the church and the ledge west of the road and but a few rods distant from the latter, penetrated 51 feet of drift before entering a very hard igneous rock. This shows a relief of at least 100 feet within a very short distance. Other outcrops occur one-half mile east of the Methodist Episcopal Church.

The main mass of the rock is a dense, very dark soda aporhyolite. Gray contorted lines of banding due to flowage in the volcanic rock characterize much of the rock east and west of the road, and at several places, particularly in the ledge west of the road, reddish knots or lumps, due to spherulitic texture, occur, surrounded by the lines of flowage. Another phase is a well-marked rhyolite breccia of angular reddish fragments surrounded by the flow structure. These various textures give the weathered surface of the rock a peculiar appearance which readily distinguishes the glacial bowlders derived from these ledges and scattered over the surface of the drift to the west, in places in great abundance. The main ledge east of the road is cut by a northeast-southwest dike of dense dark diabase.[1]

The rock in all the ledges is very hard and brittle but is crosscut by numerous joint cracks which facilitated the removal of blocks by glacial action. Striæ trend S. 75°–90° W. The dense dark rock is weathered to a depth of one-eighth inch, but no disintegrated material has accumulated on the surface of the solid rock. In places west-facing surfaces have been etched by sand blown from the surrounding plain. No exposed sedimentary rocks were noted in the vicinity, though some of the wells reach sandstone below the drift.

ARCHEAN AND ALGONKIAN ROCKS.

BARABOO DISTRICT.

TOPOGRAPHIC RELATIONS.

The Baraboo quartzite ranges of eastern Sauk County are among the most prominent topographic features of the region under discussion, and lying as they do partly within the area of the drift and extending thence westward beyond the limits of glaciation, their topographic relations to the margin of the ice sheets are of particular importance in the discussion of the glacial phenomena. Furthermore, the extensive boring being done in exploration for iron within the Baraboo basin, together with the records of many wells, has afforded data for a study of the preglacial topographic conditions. The detailed discussion of the topographic and glacial features is reserved for another connection (see pp. 169–170, 214–216, 222–227, 245–246), it being pro-

[1] Hobbs, W. H., and Leith, C. K., op. cit., p. 255. Irving, R. D., Geology of Wisconsin, vol. 2, p. 519, 1877.

posed to discuss here only the general topographic relations and the geologic character of the several rock formations exposed at the surface as a basis for the study of the glacial phenomena. The geology of this district is discussed in detail by Weidman in his bulletin on the Baraboo iron-bearing district of Wisconsin,[1] and to this work the writer is largely indebted for information supplementing his own field observations and those of his assistants. The geology about Devils Lake and The Dells of the Wisconsin is described by R. D. Salisbury and W. W. Atwood.[2] The topography and areal distribution of the several formations older than the drift are shown in Plates I and II (in pocket).

The Baraboo Bluffs, as they are often called, consist of a north range and a south range of the Baraboo Valley between the ranges to the north. The north range is narrower and lower, ranging in width from 1 to 2 miles and rises 100 to 500, mostly 200 or 300 feet, above the lower tracts on the north and the south. Through the basin between the ranges flows Baraboo River, entering through a gorge at Ableman known as the Upper Narrows, near the west end of the north range, and leaving through a gorge known as the Lower Narrows in the north range, about 6 miles east of Baraboo. A third and larger gorge cuts through the south range south of Baraboo, and in this lies Devils Lake. A fourth gorge is traversed by Narrows Creek, 1 to 2 miles west of Ableman. Neither of these gorges nor the basin between the ranges have now so great depths

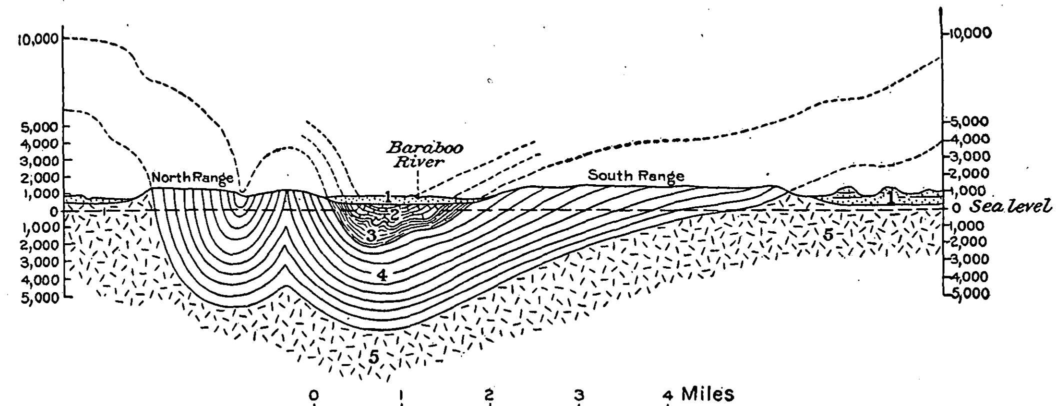


FIGURE 2.—Generalized north-south section across the Baraboo district. 1, Cambrian sandstone; 2-4, Huronian (2, Freedom dolomite; 3, Seeley slate; 4, Baraboo quartzite); 5, rhyolite and granite (Laurentian?), after Weidman.

extending about 26 miles east and west and so joined at the ends as to inclose a canoe-shaped basin 2 to 8 miles in width between the crests of the two ridges. The south range varies in width from 1 to 5 miles and rises 500 to 600 feet above the neighboring lowlands. The highest point of the south range, and also of this part of the State, is Point Sauk, 1,640 feet above the sea, which is about 4 miles east of Devils Lake in sec. 15, T. 12 N., R. 7 E. (Greenfield Township). This is also the highest elevation attained by the drift within the area under discussion, being the crest of the terminal moraine of the Green Bay Glacier where the margin of the ice lay across the ridge. Point Sauk rises about 880 feet above Wisconsin River near Merrimac, 4 miles to the south and about 800 feet above the bottom as before incursion of the glaciers and the deposition of the drift.

[1] Weidman, Samuel, The Baraboo iron-bearing district of Wisconsin: Wisconsin Geol. and Nat. Hist. Survey Bull. 13, 1904.

[2] Wisconsin Geol. and Nat. Hist. Survey Bull. 5, 1900.

BARABOO QUARTZITE.

The Baraboo ranges are the remains of great pre-Cambrian mountain folds of the Baraboo quartzite, whose flanks are overlapped by Cambrian sandstone and basal Cambrian conglomerate. Weidman has estimated the thickness of the quartzite as between 4,000 and 5,000 feet. (See fig. 2.) Overlying the quartzite in the basin between the ranges, but everywhere overlain by the sandstone and so not exposed to glacial action, are other formations. The borings made in prospecting for iron revealed the presence of the Seeley slate with an estimated thickness of 500 to 1,000 feet and the iron-bearing Freedom dolomite, consisting of dolomite, chert, slate, and iron ore and all their gradational phases, with an estimated thickness of 400 to 500 feet.

The quartzite which forms the body of the ranges is well exposed at many places, but particularly so in the sides of the several gorges. This rock is a hard vitreous quartzite, generally pinkish in color but varying through gray and pink to purplish red with some brick red and in a few places white. The bedding is generally fairly well marked and cross-bedding and ripple marks are occasionally seen. Between the massive layers of quartzite lie many thin layers of quartz schist due to shearing along the bedding planes. A great block standing near the road through the Upper Narrows at Ableman shows schistosity developed along and near the bedding planes, here nearly vertical, through a thickness of nearly 3 feet, and the same or similar zones are exposed in the west bluff of the gorge at this place. The effects of fracturing and recementation by white quartz is well shown by a large exposure of "Reibungs breccia" in the east bluff of the gorge near the railway bridge and also in a smaller way in a railway cut at the end of Devils Nose in sec. 29, T. 11 N., R. 7 E. Schist is also exposed in certain zones of shearing which cut the bedding planes at high angles at several places, particularly along the railway on the east side of Devils Lake. Contorted schist is also exposed on the north slope of the south range near the west Sauk road in sec. 15, T. 11 N., R. 6 E. (Baraboo Township). The massive quartzite, however, forms almost the whole bulk of the formation.

Microscopic examination of the quartzite shows it to be composed almost entirely of quartz grains, which have been enlarged by addition to the original grains of crystallized quartz by the further crystallization of quartz from infiltrating waters. This growth of the crystals continued until the whole became a more or less closely interlocking mass of quartz crystals with the interstices filled with a matrix or cement of fine-grained quartz. What was originally deposited as a porous sandstone has thus been metamorphosed into a very hard, dense compact quartzite.[1] Evidence of the water action in the deposition of the original sediments is seen in fine examples of ripple marks at many places, particularly in the walls of the Upper Narrows and of the Devils Lake Gorge. Those in the Upper Narrows are particularly interesting, for though originally made on the flat-lying surface of the beach sands, they are now exposed on nearly vertical faces of the rock. In the south range the rugged surfaces dip at lower angles. Layers of fine pebble conglomerate and color banding along the original planes of bedding and cross-bedding in similar positions are further evidence of the same facts.

From the correlation of the positions of the bedding planes at the many exposures throughout the district it is determined that the once flat-lying beds of ocean sands after being cemented into a quartzite were compressed and crumpled into great mountain folds of which the present ranges are but the stumps. The breccia was produced by fracturing, and the quartz schist by slipping or shearing along bedding planes and other planes of weakness where, as shown by the microscope, there was a considerable clay ingredient in the rock when the folding took place.[2]

It is not proposed in this paper to undertake a detailed discussion of the structure of the quartzite ranges, but it may be stated that there are here parts of two synclines with the intervening anticline. In the south range the dips are toward the north, usually at angles of 15° to 35°, but range as low as 5° and as high as 70°. At the outcrops in the midst of the basin and in the north range the dips are very much steeper, being largely between 60° and 90°. The low dips are best seen in the sides of the Devils Lake Gorge and the high dips in the sides of the gorges at the Lower and Upper Narrows and at Narrows Creek. At these places the beds are standing directly on edge.

As stated above, the Seeley slate and the iron-bearing Freedom dolomite, which, immediately overlying the quartzite, are not now exposed at the surface nor were they exposed to glacial action so far as known, so that they need not be considered in this connection. They constitute nearly a thousand feet of filling in the trough formed by the folding of the quartzite, having been infolded with the quartzite and later largely cut away by erosion.

The quartzite is cut by great numbers of joints crosscutting at various angles, so that

[1] Irving, R. D., and Van Hise, C. R., Enlargements of quartz fragments and genesis of quartzites: U. S. Geol. Survey Bull. 8, pp. 33-34, 1884. Also Van Hise, C. R., A treatise on metamorphism: U. S. Geol. Survey Mon. 47, 1904.

[2] Van Hise, C. R., Some dynamic phenomena shown by the Baraboo quartzite ranges: Jour. Geology, vol. 1, pp. 347-355, 1893.

the rock is broken into large and small polygonal blocks. On the steep walls of the gorges these are frequently loosened by frost action and tumble down the slopes. Such action in the Devils Lake Gorge has produced a great talus accumulation of angular blocks ranging in size from a few inches to great masses 15 to 25 feet in diameter. (See Pl. VII, *B*, p. 40.) The slopes within the limit of glaciation are much less abrupt, except within the same gorge east of the south end of Devils Lake, and it is doubtful if so great a talus accumulation occurred at any one place which was glaciated, though similar conditions of jointing on the less abrupt ledges must have resulted in a considerable accumulation of loose material ready for removal by the advancing glaciers. The cracked ledges also offered good opportunity for the removal of blocks by the plucking action of the ice.

The approximate areal distribution of the quartzite where not covered by Paleozoic formations is shown on the map (Pl. I, in pocket). As the eastern half of the range is mostly covered with glacial drift and the western half is mostly covered by loess-loam and residual clays, and as much of the area is wooded, it is not possible to determine the exact extent to which the sandstone yet overlies the quartzite, at least without a much more detailed examination of the area than the circumstances warranted. At many places within the area mapped as quartzite, especially on the broader south range, sandstone is slightly exposed in cuts along the roads, so that it is evident there is yet much sandstone, probably in patches, on the slopes and in the valleys cut in the quartzite. The occurrence of these remnants in the ravines and small valleys cutting the slopes of the quartzite ridges shows clearly that the greater part of the dissection of the ranges occurred prior to the deposition of the sandstone. The consideration of the great unconformity is, however, reserved for a later section.

Van Hise and Leith [1] report that upper Huronian (?) quartzite has been found by drilling in the deeper parts of the east end of the trough, that it overlaps the edges of all the middle Huronian (?) rocks and has conglomerate at its base, and that its thickness, as shown by the drilling, is not more than 50 feet. They state: "No exposures of the formation are recognized as such. It seems to remain simply as a residual patch in the deeper part of the trough where protected from erosion. However, some of the quartzite on the so-called Baraboo ridges may be upper Huronian (?) rather than middle Huronian (?). Still more recently red slate has been found above this upper Huronian (?) quartzite."

[1] Van Hise, C. R., and Leith, C. K., The geology of the Lake Superior region: U. S. Geol. Survey Mon. 52, p. 361, 1911.

IGNEOUS ROCKS.

Discovery.—At seven localities about the outer margin of the quartzite area igneous rocks have been found. Six of these occurrences are described by Weidman.[2] The seventh, a small outcrop of granite, occurs on the lower south slope of the Devils Nose in the N. ½ sec. 32, T. 11 N., R. 7 E. (Merrimac Township). This was discovered subsequent to the publication of Weidman's bulletin by a student whose name is not known to the writer. The location was pointed out to the writer in 1907 by F. T. Thwaites. The exposure of rhyolite at Alloa was first examined by the writer in company with C. F. Tolman in 1897, and was mentioned by Salisbury and Atwood [3] in 1900, but was first described by Weidman. The only other known igneous rock in the district whose position was published prior to the investigation of Weidman is that bordering the north side of the north range in the vicinity of the Lower Narrows, which was described by R. D. Irving.[4]

The following descriptions of the megascopic characters and stratigraphic relations are taken principally from Weidman's bulletin, and are presented to show what local crystallines must be distinguished from foreign material in studying the character and distribution of the glacial drift of the district.

Rhyolite at the Lower Narrows.—The rhyolite at the Lower Narrows is the most extensive in the area described. Weidman [5] says:

By far the largest area of igneous rock in the district is the area of rhyolite located east and west of the Lower Narrows of the Baraboo River. From the map it is seen that the rhyolite extends along the north face of the north range for a distance of over 3½ miles. Its most eastern outcrops are in the northeast corner of the SE. ¼ of sec. 23,

[2] Weidman, Samuel, The Baraboo iron-bearing district of Wisconsin: Wisconsin Geol. and Nat. Hist. Survey Bull. 13, 1904.

[3] Wisconsin Geol. and Nat. Hist. Survey Bull. 5, p. 18, 1900.

[4] Irving, R. D., Geology of central Wisconsin: Geology of Wisconsin, vol. 2, pp. 504–519, 1877.

[5] Op. cit., pp. 13–15.

and its most western are found in the NW. ¼ of sec. 20. The broadest portion lies in the N. ½ of sec. 21 and the adjacent part of sec. 16, where the exposures are distributed over the width of more than half a mile. A small area, entirely surrounded by the quartzite, lies in the vicinity of the east quarter post of sec. 20.

The rhyolite is a very hard pinkish rock, which is usually unweathered and breaks under a stroke of the hammer with a sharp conchoidal fracture. It consists of numerous crystals of pinkish feldspar and translucent quartz, which are embedded in a very fine matrix or groundmass. In places, as along the wagon road in the NE. ¼ of sec. 21, the rhyolite is very much fractured. These fractures cut the rock in all directions, so that it weathers out in small fragments bounded on all sides by plane surfaces. In other places the rhyolite is not much fractured, and when this is the case the ledges are rounded and massive. Reticulating veins of quartz from a fraction of an inch to 3 or 4 inches in thickness are quite numerous throughout the rhyolite.

The rhyolite, as already stated, is of igneous origin, and hence shows no evidence of having been deposited by water, such as bedding and stratification, which is everywhere exhibited by the sedimentary quartzite adjoining it. The rhyolite belongs to that class of igneous rocks which is of volcanic origin, in contradistinction to the deep-seated or plutonic igneous rocks represented by the granites and diorites of the district. Volcanic or extrusive rocks are delivered upon or beneath the surface by volcanic action while yet in a molten condition and spread out in streams or layers. On account of their sudden cooling, many volcanic rocks are either wholly glassy or only partially crystallized. Undoubtedly the rhyolite in this vicinity was originally only a partially crystallized rock when brought to the surface. A rough examination of the hand specimens is sufficient to show that the rock consists of two parts; one part the fine groundmass, or background, and the other the scattered crystals of pinkish feldspar and translucent quartz distributed through it. The groundmass was originally the glassy or uncrystallized portion of the rock, and the included crystals of feldspar and quartz the crystallized portion. In many places the outcrops of the area reveal fine streaks and wavy lines in the groundmass, which represent lines of flowage of the rhyolite magma as it spread out over the surface during the process of its extrusion.

At several places within the rhyolite formation are zones of rhyolite schist, consisting mainly of sericite and fine quartz. This schist is grayish and has a typical schistose or slatelike structure, and for this reason it has sometimes been called a slate. It is, however, a phase of the rhyolite formation. It occurs as a zone 150 to 200 feet wide along the contact of the rhyolite with the main body of quartzite, and also farther north in the immediate vicinity of the outcrops of conglomerate in the NE. ¼ of NW. ¼ of sec. 21. These gray sericitic schists generally, if not always, occur near the contact with the overlying pre-Cambrian quartzite or conglomerate and may in places contain some sedimentary rock, but they are mainly merely weathered and mashed phases of rhyolite.

In the earlier descriptions of this rock by Irving, Chamberlin, and Weidman the igneous rock was interpreted as younger than and overlying the adjacent upturned quartzite, the dip of whose bedding is not far from vertical. In his later study Weidman concluded that the quartzite was the younger and overlay the igneous rock, and that the conglomerate which he had previously described as volcanic breccia was in reality a basal conglomerate formed by erosion of the rhyolite in connection with the deposition of the basal sands of the quartzite formation. Concerning this he states:[1]

> The conglomerate at the base of the quartzite formation is not abundant, but on account of its character and location, it is very important since it shows conclusively the unconformable position of the sedimentary series above the igneous rocks of the district.
>
> In the vicinity of the area of rhyolite, on the north side of the north range at the Lower Narrows, several occurrences of conglomerate were noted. A considerable exposure is located on the north side of the road near the center of the NE. ¼ NW. ¼ sec. 21, T. 12 N., R. 7 E. In a former paper by the writer[2] this outcrop was referred to as volcanic breccia, which indeed it resembles very closely, since all of the fragments which compose it are phases of rhyolitic flows. However, a closer examination shows the outcrop to contain layers and thin seams made up of stratified water-deposited material, such as rounded pebbles of the rhyolite and schist, and small grains of quartz. The coarse phase of the conglomerate consists of a variety of rounded and angular fragments and pebbles from 2 to 4 inches in diameter. This outcrop of conglomerate is immediately adjacent to the rhyolite, and the character of the pebbles and fragments is such as to indicate that it is undoubtedly mainly made up of detritus from the adjacent rhyolite. On the summit and on the southwest side of the north range, in a field near the center of sec. 20, T. 12 N., R. 7 E., are numerous large blocks of conglomerate made up of various phases of rhyolite and of fine quartz rock. These blocks are immediately west, and thus in the line of glacial movement, of a small area of rhyolite surrounded on all sides by the quartzite formation, and thus very probably have not been moved far by glacial movement from conglomerate in place.

Rhyolite at Alloa.—Between 5 and 6 miles southeast of the Lower Narrows, near the foot of the south slope of the south range in NE. ¼ sec. 3, T. 11 N., R. 8 E. (Caledonia Township) is a second occurrence of rhyolite. The main ledge is a small elliptical hill a short distance northeast of the United Presbyterian Church. Other small outcrops occur at and near the foot of the slope of the quartzite range. The rock is largely a dull ashen gray on the weathered surface and darker on the fresh fracture. The porphyritic phase is not so noticeable here as a conglomeratic or brecciated phase

[1] Op. cit., pp. 26–27.
[2] Wisconsin Univ. Bull., Sci. ser., vol. 1, No. 2, pp. 44–46, 1895.

consisting of whitish fragments of banded rhyolite in a gray or darker matrix. The fragments, which vary in size from a fraction of an inch to 4 or 5 inches long, are largely angular and of various shapes and orientation, so that surfaces where the differences in color and texture between fragments and matrix is emphasized by weathering have a very peculiar appearance. Weidman[1] states that "thin seams and beds of slate and arkose are interstratified with the coarse conglomerate and prove conclusively its sedimentary nature." This conglomerate he interprets as basal to the quartzite formation and marking the unconformity. The quartzite has not, however, been observed overlying the rhyolite.

The rhyolite is cut by numerous joints and the surfaces of the ledges are hard and smoothed as by glaciation. Loose blocks of the rhyolite occur in the vicinity, but disintegrated rhyolite was not noted. A well at one of the houses about 60 rods southeast of the ledge penetrated drift to a depth of 100 feet, or to a level about 140 feet lower than the crest of the rhyolite where sandstone was encountered.

Granite in Merrimac Township.—There is one other outcrop of crystalline rock within the limits of the drift. A patch of granite, rather fine grained and red, occurs near the foot of the lower south slope of the Devils Nose, a few rods north of the road corner in N. ½ sec. 32, T. 11 N., R. 7 E. (Merrimac Township). It is also slightly exposed about 80 rods east of the corner but the exposure at neither place is sufficiently good to show the relations of the granite to the quartzite.

Granite in Sumpter Township.—Between 5 and 6 miles west of the exposure cited above, a short distance north of Meyers Mill in the SW. ¼ sec. 33 and SE. ¼ sec. 32, T. 11 N., R. 6 E. (Sumpter Township), is a small area of granite. The exposures occur in the lower part of a valley cut in the south slope of the south range and drained by the main branch of Otter Creek, and form low hills over an area of 10 or 20 acres. The megascopic characters of the rock are described as follows by Weidman,[2] who discovered the exposures:

The granite is a medium to fine grained variety, varying in color from grayish to reddish, and consists of feldspar, quartz, and a small amount of dark mineral. The granite forming the knob on the southwest side of the creek is much fractured and jointed, and as a result it weathers into angular pieces. The granite on the east side of the creek, at the base of the quartzite bluff, is somewhat schistose and is considerably weathered. At first sight it was thought this weathered, schistose phase might be arkose, but the microscopic examination shows it to be a much weathered and mashed phase of the granite formation. This schistose phase of the granite forms a zone between the massive granite on one side and the massive quartzite formation on the other, similar to the zone of weathered rhyolite schist occurring between the massive rhyolite and the quartzite at the Lower Narrows.

Just below the road at the west end of the exposure the writer observed a small outcrop of dense dark-greenish diabase. This may be a dike cutting the granite, but as the contact was not exposed the exact relations were not determined. F. T. Thwaites stated in a personal communication to the writer, under date of April 22, 1908, that Mr. Steidtmann, of the University of Wisconsin, had "discovered positive evidence that the red granite at Meyers Mill is an intrusive in the quartzite in the shape of granite veins at an outcrop on the east side of the valley." As is shown in a subsequent connection (p. 67) this occurrence of granite veins intrusive in the quartzite is in consonance with similar granitic intrusions in the quartzite of the Waterloo area. This being the case the granite near Meyers Mill can not be considered as older than and basal to the quartzite.

Rhyolite near Denzer.—Weidman found rhyolite about 1½ miles northeast of Denzer in the SE. ¼ sec. 11, T. 10 N., R. 5 E. (Honey Creek Township), on the Markert farm, which he describes as follows:[3]

Numerous loose blocks occur at this place along the road at the bridge and farther northeast along the stream. The largest outcrop is a small, nearly flat ledge forming the northwest bank of the stream, about 150 yards above the bridge. It is not unlikely that a thorough search would reveal other outcrops of rhyolite in this vicinity.

The rhyolite of these outcrops varies from a very fine grained rock, having very few phenocrysts of feldspar, to a coarser rock, having abundant porphyritic crystals of feldspar. Quartz phenocrysts are present but not abundant.

Diorite near Denzer.—The only diorite known in the district is that found by Weidman, one exposure being near the center of the SE. ¼ sec. 9, T. 10 N., R. 5 E. (Honey Creek Township), on the Mellenthein farm, and the other about a mile farther northeast (about 1¼ miles

[1] Op. cit., p. 27.

[2] Idem, p. 20.

[3] Idem, p. 17.

north of Denzer) in sec. 10. The megascopic character and relations of this rock are described as follows:[1]

The diorite on the Mellenthein farm forms a low knob 30 or 40 feet above its surroundings, showing several well-exposed ledges of the massive diorite. The diorite along the road north of Denzer appears in numerous large blocks; and since hard, crystalline rock is reported to have been struck in the wells at the farm houses a few rods distant, it is probable that diorite in place occurs not far below the surface in the vicinity. * * * Large blocks and bowlders of the diorite are scattered along the adjacent hillsides also, but these latter are believed to have been moved from the parent ledge by glacial movement, as they occur with various other kinds of bowlders.

WATERLOO DISTRICT.

QUARTZITES AND ASSOCIATED ROCKS.

Distribution and character.—Thirty to forty miles southeast of the Baraboo district in the adjacent townships of southwestern Dodge County and northwestern Jefferson County are several groups of ledges of quartzites which resemble in character and probably correspond in age with the quartzite of the Baraboo district.

These main exposures were first described in detail by Chamberlin[2] in 1877. Later they were described, with the addition of the Mud Lake ledges, by I. M. Buell,[3] following a study of the Waterloo quartzite ledges and the bowlder trains derived therefrom which was carried on under the direction of Chamberlin for the United States Geological Survey. The descriptions of the ledges presented below are compiled from the field notes of the writer and his assistants, from the above-noted publications, and from Buell's unpublished manuscript and notes. The results of a later study by J. H. Warner are published in the Mining World.[4]

The ledges are considered, according to their geographic distribution (Pl. I), in four groups, designated the Portland, Hubbleton, Lake Mills, and Mud Lake. Two of these were described by Percival; the third was found by Chamberlin during his study of the region; and the two exposed ledges of the fourth were discovered by Buell during his investigations. The location of the three buried ledges north of Mud Lake was ascertained by the present writer from information furnished by the drillers and owners of wells in which the rock was encountered. Owing to their importance in connection with a study of the glacial bowlder trains a somewhat detailed description of the several ledges and of their relations to the topography and adjacent formations is presented here.

These ledges are but the exposed crests of nearly buried remnants of great Huronian mountain folds, such as are represented by the Baraboo Bluffs. They were exposed when erosion prior to the advent of the glaciers had denuded their vicinity of all but scattered remnants of the Trenton limestone and was cutting away the friable layers of the St. Peter sandstone and trenching the underlying Lower Magnesian limestone. As they now protrude from the enveloping drift the ledges occur on the borders of a connected series of marshes, above which they rise in very moderate relief. All of the exposures occur between elevations of 780 and 900 feet above the sea.

The rock exposed in all the ledges is a rather pure vitreous quartzite, carrying small amounts of accessory minerals, chiefly of secondary origin. In consequence of the enlargement of the quartz crystals by infiltration of silica-bearing waters and of dynamic metamorphism, the clastic structure usual in quartzites is very largely obliterated, so that under the microscope the rock is in large measure crystalline throughout. At many places bedding planes and cross-bedding are marked by an alternation of fine and coarse material or by color bands. At other places there is little or no indication of the original stratification. In places along the bedding planes and elsewhere schistosity has been developed as the result of shearing when the folding of the beds occurred. The rock is rather brittle, being cut by abundant seams, and joints and finer cracks appear on the glacially smoothed surfaces. Little alteration has taken place as the result of weathering.

The clusters of outcrops are divided geographically as well as by slight structural differences into four groups, here designated the Mud Lake, Portland, Hubbleton, and Lake Mills ledges.

Mud Lake ledges.—The most northeasterly of the quartzite exposures of this district

[1] Weidman, Samuel, op. cit., p. 18.
[2] Chamberlin, T. C., Geology of Wisconsin, vol. 2, pp. 252-256, 1877.
[3] Buell, I. M., Geology of the Waterloo quartzite area: Wisconsin Acad. Sci. Trans., vol. 9, pp. 255-274, 1892.
[4] Warner, J. H., The Waterloo quartzite: Mining World, vol. 22, No. 16, pp. 420-422, 1905.

occurs on the east margin of the marsh in which lies Mud Lake, in the NE. ¼ sec. 2, T. 9 N., R. 14 E. (Shields Township), about a mile northeast of the point where the La Crosse division of the Chicago, Milwaukee & St. Paul Railway crosses the marsh. The exposure is a small low ledge, less than 4 acres in extent and rising barely 5 feet above the marsh level. This broad marsh and lake tract probably marks the location of a preglacial valley tributary to the ancient Rock River valley. (See Pl. II, in pocket.) The surface of the ledge is somewhat rounded and very well smoothed by glacial action. The rock has a highly vitreous luster, a rather coarse but indistinctly granular texture, and ranges in color from almost pure white, through gray, pinkish, reddish, and bluish to a dark purplish. In places it is darkly banded along what appear to be the bedding planes. There is little evidence of dynamic metamorphism. Slight schistosity is marked by thin seams of reddish iron oxide. The prevalent dark purplish tint is sometimes oxidized to a reddish tint on the surface. Twenty readings on the strike of the beds gives an average of N. 61° E. The beds dip about 41° SE.

A well at a house about 40 rods east of the ledge is said to have penetrated 108 feet of drift without encountering rock, and Joseph Plasil's well, 80 rods south of the ledge, penetrated drift and sandstone to a depth of 200 feet. Frank Plasil's well, three-fourths of a mile south, is stated by the owner to have penetrated the following deposits:

Log of Frank Plasil's well, in the NE. ¼ sec. 11, T. 9 N., R. 14 E. (Shields Township).

	Feet.
Drift	60
Thin shaly limestone (Trenton?)	A few.
Sandstone (St. Peter)	?
Flinty rock (Lower Magnesian)	A few.
White sandstone (Madison)	?
	210

The west ledge of the Mud Lake group is an island in the marsh in sec. 3. T. 9 N., R. 14 E. (Shields Township), about 1⅞ miles south of west of the east ledge. This west ledge has a length of about 60 rods from north to south and a breadth of about 20 rods, being ovoid in outline. Its sides rise rather abruptly from the surrounding marsh, though the highest points are only 10 or 12 feet above the marsh level. The surface of the ledge, which has the form of a low swell, is largely covered by soil and trees, most of the exposures being on the northwest margin. The rock is about the same in character as that at the east ledge, though somewhat finer in texture and more uniform in color, being mostly dark bluish or purplish. The strike of the beds averages about N. 39° E. and the dip about 44° SE.

Both of the ledges are crisscrossed by joints, in places less than an inch apart but commonly more. The joints are mostly open and their faces smoothly cut, with high angles of dip. The majority of over 180 readings on the principal joint faces range between N. 40° W. and N. 80° W., though about all points of the compass are represented. Of 36 readings on secondary joints the majority range between N. 30° E. and N. 80° E. Some older joints occur recemented by white quartz and cut through by the later set. At one point on the west ledge the dark-blue rock is brecciated and recemented with white quartz.

Under the microscope the single quartz individuals are comparatively large, many of them showing areas of 5 to 6 square millimeters. No trace of the original clastic structure is now visible. The outlines of the quartz grains are irregular, and their secondary growth has produced a closely interlocking crystalline texture with very little interstitial material. A few small quartz grains are entirely inclosed by the growth of their larger neighbors. Fluid, sericite, and magnetite inclusions also occur in the quartz grains, and a small amount of sericite and magnetite occurs interstitially.

The smoothed and rounded surfaces of the ledges show grooves and scratches due to glaciation. The trend of striæ on the east ledge is S. 5° W. and on the west ledge S. 6°–11° W.

With the Mud Lake ledges may be grouped several ledges found beneath the drift in wells within 3 miles north and northwest of Mud Lake. The approximate location of these ledges is shown on Plate I (in pocket), but, as they are buried beneath the drift, it is impossible to determine their extent from surficial observations. J. V. Roller, well driller, Beaver Dam, Wis., informed the writer that he encountered white quartz rock in several wells on farms between 1 and 2 miles southwest of Reeseville in adjacent parts of secs. 32 and 33;

T. 10 N., R. 14 E. (Lowell Township), and sec. 5, T. 9 N., R. 14 E. (Shields Township). In two of these the quartzite underlay 12 and 60 feet of drift. In one of them 10 to 15 feet of sandstone (St. Peter) intervened between the drift and the quartzite, and in another the quartzite lay beneath 90 feet of drift and sandstone. The following deposits were penetrated in Thomas Yauman's well in the NW. ¼ NW. ¼ sec. 5, T. 9 N., R. 14 E. (Shields Township).

Log of Thomas Yauman's well, 2 miles southwest of Reeseville, Wis.

	Feet.
Drift	75
"White quartz" (quartzite)	100
Very hard rock, "black"	2
	177

A sample of fine drillings from the "black" rock was identified by E. S. Larsen, jr., as dioritic material. This may represent a dike cutting the quartzite or the basement crystalline underlying the quartzite.

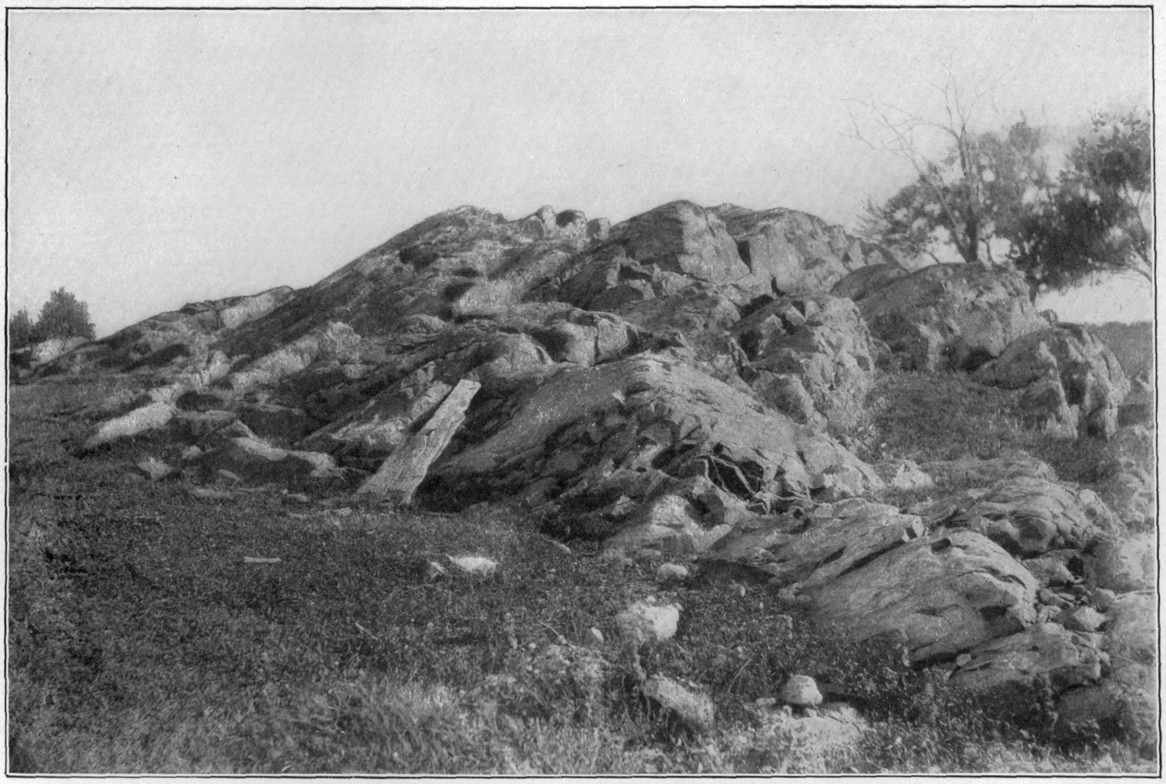
Mr. Roller states that about a mile south of this area, at Henry Klug's, in the SE. ¼ NE. ¼ sec. 8, T. 9 N., R. 14 E., and about a mile southwest of the ledge, exposed as an island in the big marsh, he found blue quartz rock beneath 97 feet of drift and 100 feet of flinty rock, which may belong to the Lower Magnesian limestone, as it is at about the proper horizon. Between 1 and 2 miles southwest of Thomas Yauman's place in secs. 1 and 12, T. 9 N., R. 13 E. (Portland Township), Mr. Roller encountered quartzite beneath the drift in three wells, in two of which the drift was 60 to 68 feet thick. About a mile farther southwest, in the SE. ¼ sec. 14, at Gottfried Winter's place, two of the wells were said to have encountered red rock like that at the Portland quarry—that is, quartzite—beneath 36 to 47 feet of drift. In one of these with the red rock was "white flint." About 2 miles northwest of this tract, in the SW. ¼ NW. ¼ sec. 2, S. M. Austin's artesian well is said to have penetrated quartzite beneath 90 feet of drift and 605 feet of limestone and sandstone.

Several wells within a mile north of the west half of Mud Lake, in secs. 17, 18, and 19, T. 9 N., R. 14 E. (Lowell Township), were said by their owners to have encountered "granite," probably quartzite, below 40 to 110 feet of drift, and the overturning of trees in a small grove in SE. ¼ NE. ¼ sec. 18 was said to have disclosed a ledge of "granite." Careful search in this vicinity by the writer failed to reveal any rock which was surely in place, but revealed abundant angular blocks of red quartzite and some white quartzite in the grove in such condition as to make it very probable that a ledge of quartzite lies below a thin covering of drift. Henry Hamman's well on the slope of the hill just north of Mud Lake, in the SW. ¼ sec. 17, is said to have penetrated 4 feet of hard rock, probably quartzite, beneath 111 feet of drift and 49 feet of red sandstone (St. Peter).

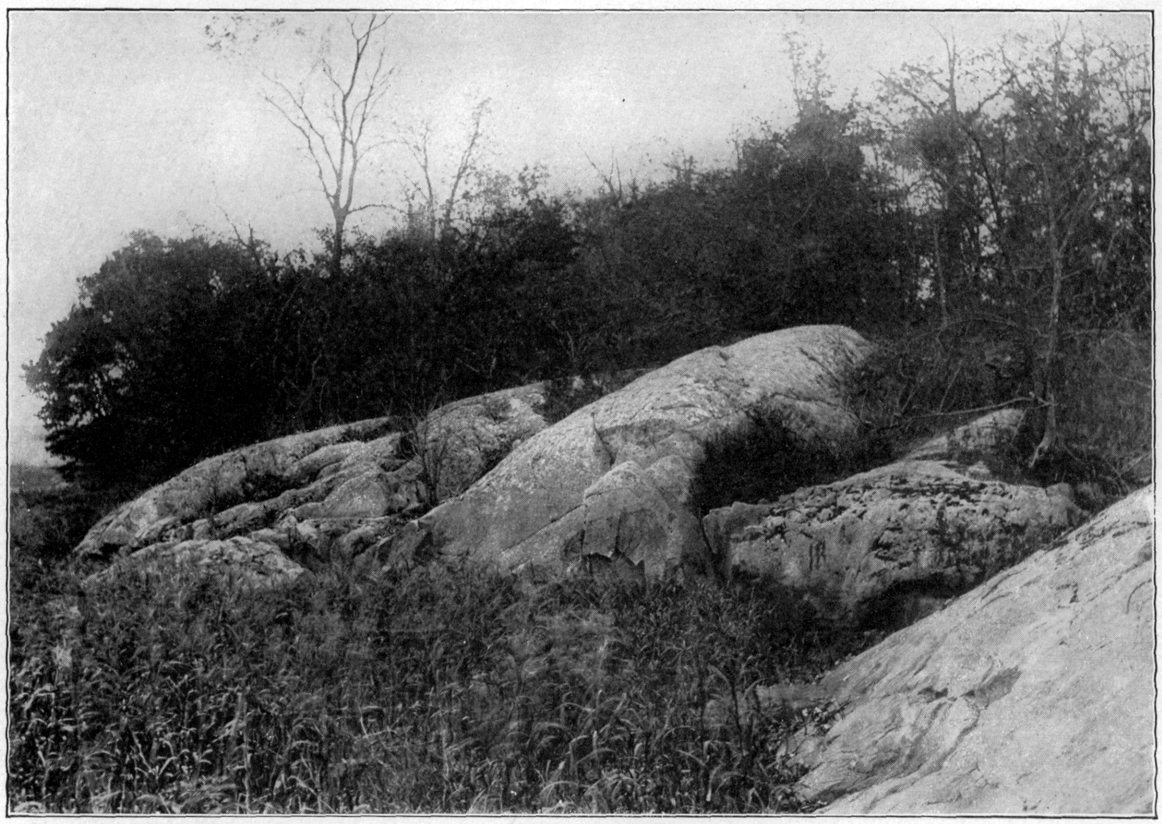
From these records it appears that the formation enveloping the slopes of these buried ledges beneath the drift is sandstone, probably St. Peter. Not far from the buried ledge on the east side of a small ridge bordering the marsh in the NE. ¼ SE. ¼ sec. 17, Trenton limestone is slightly exposed about 5 feet above the marsh. Limestone has been quarried here and is said to have exposed the St. Peter sandstone below.

Several wells in the southeastern part of sec. 26 and the northern part of sec. 35, T. 9 N., R. 13 E. (Portland Township), have revealed another buried ledge, which was exposed to glacial abrasion. The abundance of fragments of red quartzite in the road and gullies in the middle of sec. 35 led Buell to conclude that this ledge was the source of the red quartzite found in the drift, for which no exposed parent ledge had been discovered. It is probable, however, that at least one ledge of red quartzite occurs farther north in sec. 18, T. 9 N., R. 14 E. (Lowell Township), and it is possible a considerable area of this may have been exposed to glacial abrasion.

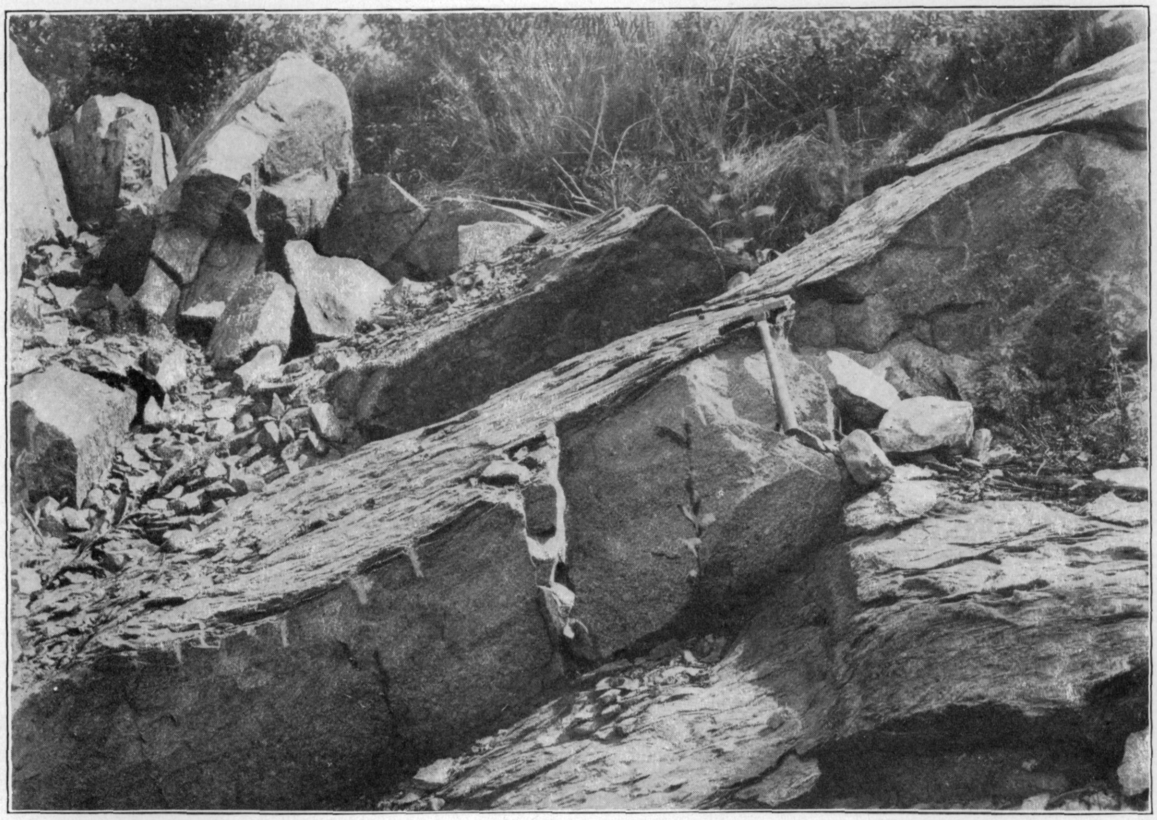
This red quartzite is of a type more or less distinct from that found at the exposed ledges. It is pinkish gray or dull reddish, is fine textured, has low translucence, and appears granular on fresh fractures. On certain surfaces the arrangement of the interstitial material gives a schistose appearance. In microscopic sections the quartz grains appear as very small individuals, not usually exceeding one-fifth millimeter in diameter. They are very uniformly distributed with a comparatively large amount of interstitial material, chiefly sericite. This rock resembles the Portland ledges in composition, but in general appearance it is more like that of the Hubbleton ledges.



A. LEDGE OF QUARTZITE 2 MILES WEST OF HUBBLETON, WIS.



B. QUARTZITE AT NORTH SIDE OF STONY ISLAND 4 MILES NORTHEAST OF WATERLOO, WIS., SHOWING GLACIALLY SMOOTHED SURFACE.



A. SCHISTOSITY DEVELOPED IN QUARTZITE BY SHEARING ALONG BEDDING PLANES IN O'LAUGHLIN'S QUARRY 2½ MILES NORTHEAST OF WATERLOO, WIS.

B. BASAL CONGLOMERATE ON NORTH SLOPE OF WATERLOO QUARTZITE AT HORIZON OF ST. PETER SANDSTONE, ROADSIDE GULLY *IN SECTION* 27, PORTLAND TOWNSHIP, DODGE COUNTY, WIS.

Hubbleton ledges.—So small a part of the total area of quartzite is now exposed to observation that all the structural relations can not be made out, but as the dip at most of the exposures is in general easterly, with variations from southeast to northeast, it is inferred that the uppermost rock is exposed in the eastern ledges. The ledges composing the Hubbleton group are therefore supposed to be the highest beds exposed and are next considered.

The most northerly exposure of the group occurs in the south slope of the ridge terminating in the NW. ¼ sec. 36, T. 9 N., R. 13 E. (Portland Township). The rock at this place is dark bluish gray to drab quartzite. At one point it is brecciated and recemented with white quartz. The surface of one block which is not certainly in place is beautifully ripple-marked. In a small gully a little to the west is a slight exposure of much shattered vitreous quartzite of a reddish color. What appear to be bedding planes at these exposures strike N. 4°–8° E. and dip 35° SE.

At the east line of the SE. ¼ sec. 35, on the east border of the marsh, just south of the road, one of the largest exposures of the Hubbleton group, measuring 50 to 75 feet north to south, rises about 15 feet above the line of the marsh. The rock is finer grained and more vitreous than that of the Portland ledges and varies in color from pinkish to drab. The bedding here is plainly marked, dipping 27° E. on an average and striking about N. 9° W. The rock is closely crosscut by three sets of joints, striking N. 60° W., N. 32° E., and N. 83° E., and dipping respectively 86° NE., 80° NW., and 88° S.

Owing to the exposure of the edges of the beds and to the abundant cross fractures the conditions were exceptionally favorable for plucking by the glaciers, so that the surface has the appearance shown in Plate VIII, *A*, only the corners and edges being rounded.

A notable feature at this point is the large accumulation of quartzite bowlders, mostly angular, immediately in lee of the ledge, where they form a ridge tailing out several rods to the southward until they disappear in the marsh.

On the ridge to the east, in the SW. ¼ sec. 36, are slight exposures of darker purple banded quartzite and of dark translucent quartzite.

Half a mile south, on the west side of the marsh, a ledge of quartzite projects from the lower east slope of a large ridge. The smoothly rounded rock surface, which has a length of about 300 feet and a breadth of 70 feet, rises 20 to 25 feet above the marsh level. A quarry here gives a good exposure of the rock, which is highly vitreous, translucent, and varies in color from pinkish to bluish gray. The rock is brittle and breaks into angular wedge-shaped fragments along the numerous cracks and joints. The bedding, which is well marked, strikes N. 12°–22° E., and dips 22°–27° SE. The rock is cut by three sets of joint planes, striking N. 63° W., N. 70° W., and N. 22° E., and dipping respectively 86° NE., 40° SW., and 90°. Glacial striæ on the several ledges range from S. 20° W. to S. 33° W.

Microscopic examination of this rock shows almost no trace of the original clastic structure. Interstitial material occurs in but very small amounts, the rock being almost wholly quartz, the larger grains having very irregular outlines and elongated forms. These larger grains have their longer axes generally parallel, the interstices being filled principally with fine quartz granules. Here and there fine grains of magnetite and small patches of sericite occur interstitially. Zircon crystals occur as inclusions in the larger grains.

Portland ledges.—The Portland group of ledges, the largest in the Waterloo district, has been the most carefully studied and may be considered the most important. It consists of Stony Island ledge, at the north, at the junction of Waterloo Creek and Crawfish River, in the NW. ¼ sec. 27, T. 9 N., R. 13 E. (Portland Township); of the quarry ledge 1½ miles south and 1 mile east of the village of Portland, in the SE. ¼ sec. 33; and of numerous small ledges outcropping in adjacent sections in the vicinity on the west slope and crest of the upland lying east of the broad marsh.

These ledges lie along the crest and upper part of the east slope of a preglacial valley which was originally tributary to the ancient Rock River. (See Pls. I and II, in pocket.) It appears from information obtained concerning numerous wells in the vicinity that quartzite underlies the drift throughout much of the area east of this line of outcrops for about 2 miles to and including the line of the Hubbleton ledges. This includes one patch of overlying sandstone and possibly others. The overlying drift is reported as varying in thickness from nothing to 85 feet, so that it is practically impossible to determine the exact area of quartzite which was exposed to glacial action.

Stony Island, the most northerly exposure of the Portland ledges, lying at the junction of Waterloo Creek and Crawfish River, has a north-south length of about 72 rods, an east-west breadth of 60 rods, and an area of approximately 25 acres. The highest points of its rounded surface rise 40 feet above the level of the surrounding marsh and streams. About the north end the bare, smoothly rounded, and polished rock surface rises in places abruptly from the surrounding marsh and water. (See Pl. VIII, *B*.) The average of a number of readings taken on what appear to be bedding planes marked by banding and layers of fine quartz pebbles shows that the beds on the island ledge strike about N. 40° E. and dip 27° SE. The thin drift which covers most of the surface supports a vigorous growth of trees. It contains a little gravel and a few foreign crystalline bowlders.

About one-fourth mile northeast of Stony Island, on the east side of Crawfish River, in the SW. ¼ sec. 22, there are two small exposures of what appears to be the top of a quartzite ledge.

South of Stony Island, beyond the marsh and creek, in a gully near the road corner, a conglomerate (see p. 69) composed of quartz pebbles in a matrix of sandstone is exposed continuously up the slope in the gully beside the road to a height of 50 or 60 feet above the creek. At this elevation the conglomerate ends and numerous small, smoothly glaciated surfaces of quartzite are exposed. A slight outcrop of this conglomerate also occurs in the slope about 80 rods southwest. From the limit of the conglomerate southward for nearly 1¾ miles quartzite is exposed in many places in the west slope and at the south on the crest of the ridge. The bedding is nowhere very plainly marked in these small exposures, though there appears to be a general easterly dip. Eight readings, taken mostly on layers of small quartz pebbles which appear to mark the bedding, show the strike to range from N. 60° W. in the SW. ¼ sec. 27 to N. 30° E. in the SW. ¼ sec. 34, and to dip 10° to 49° NE. or SE. The area outlined by these ledges has been estimated as about 180 acres. The drift surface adjacent to this line of outcrops on the east is marked by drumloidal swells rising 20 to 100 feet above the quartzite ledges.

Just west of the slope marked by the southern half of this line of outcrops is the quarry ledge, the largest and most important of the group. It occupies the eastern part of the SE. ¼ sec. 33 and extends slightly into adjacent sections on the south and east. Its longer axis lies generally parallel with the strike of the beds in a northwest-southeast direction. Its length is about one-half mile, its greatest breadth is about 80 rods, and its area is about 50 acres. The east slope of the ledge is rather abrupt, corresponding with the dip of the beds. From the crest, which in its highest part is about 45 feet above the marsh, there is a more gradual slope to the southwest border of the marsh. The greatest part of the ledge is thinly covered with drift. Where exposed the surface of the rock is gently undulating, smoothly rounded, and in places beautifully polished as the result of glaciation. The quarry of John O'Laughlin in the east side of the ledge affords good exposures of the structure and bedding of the rock.

The rock exposed in all the ledges of the Portland group is of the same general character. It varies from comparatively fine grained quartzite to conglomerates containing pebbles 2 inches in diameter. Its color is mostly light gray or light bluish gray to drab, becoming bluish to purplish in the eastern outcrops. The quartz crystal grains which compose the bulk of the rock are somewhat grouped in irregular clusters with secondary sericite interspersed between the clusters, giving a slightly mottled appearance to the rock.

The conglomerate layers are for the most part confined to this group of ledges. In the southernmost exposures the rock is chiefly a conglomerate, but at the quarry and in the exposures to the north fine-grained and pebbly layers alternate in the bedding and cross-bedding as in beach structure. In the coarser conglomerate layers the matrix is largely made up of sericite wrapped about the pebbles, which are chiefly of glassy quartz of lighter color than the matrix but which include a little gray micaceous material, red jasper, and black magnetite, with associated hematite. A much coarser conglomerate than any exposed in the ledges appears in considerable abundance in the bowlder trains and indicates concealed ledges at a lower horizon. The occurrence of these conglomerates on the west margin of the ledges indicates the near approach of the strata to the contact of an older formation from which the pebbles have been derived. Similar conglomerate appears in the train from the Mud Lake ledges, but none is exposed in these latter ledges themselves.

As seen in microscopic sections the quartzite of the Portland ledges is for the most part of finer grain than that of the Mud Lake rock, the particles of quartz varying in size from 1 millimeter downward to the limit of determination. These grains show some tendency toward grouping in clusters in which the crystals are closely grown together. They are of irregular form but are less intricately intergrown than in the rock of the Mud Lake ledges. Zircon and magnetite occur as inclusions but not abundantly. Quartz and magnetite are intermingled with the interstitial sericite, which appears in distorted forms between the quartz areas. Hydrated iron oxide is also occasionally seen. Almost no trace of the original clastic structure of the rock is visible.

Observations on the strike and dip of the beds in the quarry ledge show a somewhat complicated structure. An average of 20 readings indicates a general trend of N. 48° W. and a dip of 10° to 79° NE. The extreme variations of the strike noted were due north and N. 75° W. At some places a considerable variation in both dips and strikes occurs within the space of a few yards. The structure seems to indicate that the Portland group of ledges lies at the extremity of a pitching syncline, or possibly a synclinorium, which may account for the considerable amount of dynamic metamorphism which has taken place.

The effects of dynamic metamorphism are shown by the development of a schistose structure in the quartzite and by the complete conversion of parts of it into mica schist. Most of these zones of schistosity correspond with the bedding shown by banding and by layers of pebbles, the change evidently being due to the upward shearing of higher beds upon the lower in the process of developing the folds. (See Pl. IX, *A*.) In many places a zone less than a foot in thickness shows all stages of the transition from quartzite which to the naked eye appears unchanged, through quartzite in which incipient cracks appear, to quartzite with mica developed along the lines of schistosity, to gray or greenish mica schist with no semblance to the original rock, and again back to the unchanged quartzite on the other side.

Shearing has taken place along a few of the white quartz veins, which in many places cut the quartzite, as though these were lines of weakness. In such places the quartz filling is apt to be broken up and the fragments enveloped in mica schist. Where shearing took place along layers of pebbles these are enveloped in mica schist and some of them are flattened, with schistosity developed parallel to their longer diameters. The middle of one prominent zone of fracture, shear, and schistosity is occupied in part by 6 to 8 inches of soft grayish schist and fine whitish clayey material of talcose feel. The rock on either side of this zone is so cracked in every direction that it can not be used for paving blocks.

All of these ledges are considerably broken by joints whose faces are smooth and clean-cut and for the most part dip at high angles. A total of more than 300 readings taken on the strikes of these joints shows that though they radiate to nearly all points of the compass they tend markedly to group in two principal sets approximately at right angles to each other. The following list shows the average strike of the joints in the several ledges of the Portland group:

Stony Island ledge	N. 65° W., N. 6° W., N. 26° E.
Quarry ledge	N. 38° W., N. 61° E.
Minor ledges	N. 43° W., N. 42° E.

These several averages vary less than 15° from being parallel with or normal to the average strikes of the beds in the several ledges.

An older set of fractures has been recemented by white quartz. In some places the surface is thickly gashed with these veins, and at one point a breccia was seen. At one or two places in a zone of schistosity the quartz filling of gash veins contained also crystals of pinkish feldspar, mica, and hematite.

At the northeast extremity of Stony Island the quartzite is cut by a pegmatite vein 3.2 feet thick, which is exposed through a distance of 96 feet. The strike of this vein is about due west and the dip is 70° N., which is nearly normal to the bedding of the quartzite. On the north side the quartzite has cracked off, but on the south side the contact with the bounding wall is sharply defined. About 20 rods south a similar vein 13 inches thick is exposed in the slope for 75 feet. The strike of this vein is N. 47° E. and the dip 24° NW. A few rods west of these a third vein 8 inches thick was observed.

These veins are of very coarse grained pegmatite, consisting of feldspar, quartz, and mica, in the order of their abundance. The feldspar, which is of a pinkish or flesh tint, occurs in large crystals, many of them more than 2 inches in diameter. One large twinned feldspar 6 inches long and 3 inches wide was observed only a few inches from the south wall of the vein. The quartz, which is white to grayish in color, is largely in irregular masses between the feldspars or inclosed within them. The mica, which is of a light-greenish tint, occurs in flakes and prisms, some of which have transverse dimensions as great as three-fourths by 1½ inches. The appearance of this rock is very striking, and bowlders derived from it would be readily recognized. The occurrence of a few bowlders of similar pegmatite on the opposite side of the river near the small ledges in the SW. ¼ sec. 22 suggests that the larger vein may be continuous beneath the stream or that the bowlders may have been transported across it.

These veins of granite cutting the quartzite are particularly interesting as showing that igneous intrusion took place in this region subsequent to the deposition of the quartzite formations. That it took place subsequent to the metamorphism of the original sandstone into quartzite is probable because of the sharp line of contact at the walls of the veins with no apparent dissemination of the granitic material through the adjacent quartzite. It is not known that the intrusion occurred subsequent to the deformation of the formation. Indeed, there is some indication that it did not, for at one point in the quarry ledge traces of similar pegmatitic material were found wrapped in mica schist in one of the zones of shearing.

The ledges of the Portland group show the effects of glaciation very markedly in their smoothed, round, polished, and striated surfaces. The action of the water, possibly glacial water, is also seen in numerous small potholes in the rounded surfaces of the ledges. Glacial striæ observed on the Island ledge trend S. 20°–36° W., on the minor ledges S. 5°–20° W., and on the quarry ledge S. 15°–29° W.

The stratigraphic relations of the quartzite ledges so far as known to the writer are shown

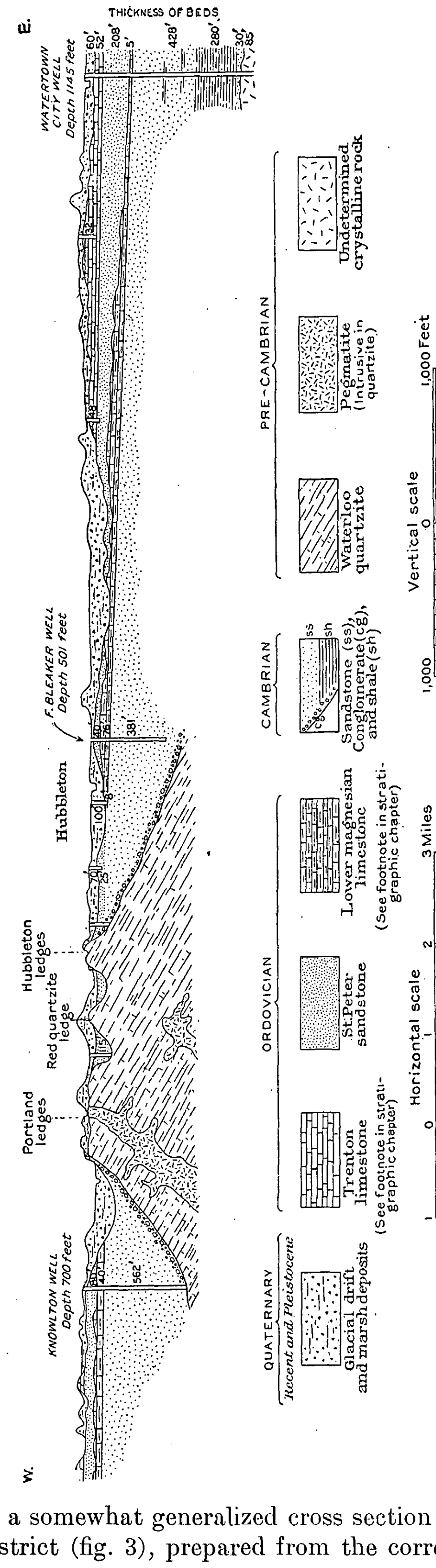


FIGURE 3.—Diagrammatic section showing the relations of the Waterloo quartzite to surrounding formations.

in a somewhat generalized cross section of the district (fig. 3), prepared from the correlation of surficial observations and data afforded by the drilling of wells. On the map and cross sections accompanying Warner's paper[1] the presence of dolomite, iron formation, and slate are shown overlying the quartzite buried beneath the Paleozoic sediments. As stated in the article, however, these drawings show "the possible occurrence of other pre-Cambrian formations above the basal quartzites on the basis of the correlation with the Baraboo series." So far as known to the writer, the presence of such deposits has not been revealed by any borings. More detailed investigations, as by boring with the diamond drill, may reveal conditions similar to those found in the Baraboo district. Indeed, it is quite possible that formations, possibly of economic value, such as were discovered at Baraboo, lie deeply buried in the structural basin in the Waterloo district. Warner states:

> Magnetic surveys with the solar compass and a dip needle were made across the belt where the iron formation should theoretically occur. No attraction was noted. This was not unexpected, since if any iron ore were present it would probably be in the form of hematite, as at Baraboo, where also no magnetic variation can be observed.

A general knowledge of the Baraboo and Waterloo districts, however, affords no grounds for expecting that such deposits would be found by drilling outside—that is, north or west of—the rim of the structural basin, as has been done by some prospectors. Referring to the Waterloo quartzite area in 1911 Van Hise[2] and Leith state that well drilling outside of the Waterloo synclines shows the presence of a granite basement. Reference is probably intended to the crystalline rock reached by the Watertown well. It is not, however, the purpose in this paper to discuss more than the general stratigraphic relations of the ledges as a whole.

Mention has already been made (p. 66) of a conglomerate exposed in the gully in a slope near the corner in the middle of the W. ½ sec. 27, T. 9 N., R. 13 E. (Portland Township), to a height of 50 or 60 feet above the level of the marsh. For some distance this conglomerate consists of large and small, well-rounded bowlders and pebbles of quartzite embedded in a matrix of coarse light-colored sandstone. (See Pl. IX, *B*.) Some of the larger bowlders measure 3 to 6 feet in their longer diameters. Down the slope to the north, farther from the quartzite, the average size of the bowlders rapidly decreases. Halfway down the largest pieces are only 3 to 4 inches in diameter. At the corner near the creek the bulk of the pebbles are still smaller. In some places on the slope the larger quartzite bowlders are surrounded by bands 2 inches thick of thin layers of quartzite apparently scaled off by concentric exfoliation. Incipient cracks also occur in the solid nuclei concentric with the outer bands. This condition is probably the result of weathering and of expansion and contraction of the dense quartzite in the more porous matrix. Both quartzites and matrix of the conglomerate exposed in this gully are planed nearly flat, smoothed, and striated. About 20 rods east of the corner the conglomerate is again exposed in a gully in the south bank of the creek. At this place, as higher up in the road, large quartzites occur. A few rods farther east a small quarry hole exposes sandstone comparatively free from quartzite pebbles or bowlders, but digging has revealed large well-rounded quartzite bowlders, some of them 5 or 6 feet in diameter. At these exposures the sandstone is largely perforated by worm borings (*Scolithus*).

The age of this conglomerate is not certainly known. It, as well as the red sandstone exposed in the railway cut about one-half mile southeast of the most southerly exposure of the quartzite of the Portland ledges in the SE. ¼ sec. 3, occurs at about the level corresponding to the St. Peter sandstone in the surrounding areas. No fossils other than *Scolithus* have been found, and the stratigraphic relations of the several formations in the surrounding areas are not such as definitely to determine whether it is the shore formation of the St. Peter sandstone, the Lower Magnesian limestone, or the upper part of the Cambrian sandstone. This conglomerate and its talus probably contributed well-rounded quartzites to the drift. The bowlder trains from the ledges of the Portland group are the most pronounced in the district.

A comparison of the cross section with conditions in the Baraboo district (fig. 2, p. 57) shows that had erosion prior to the advent of the glaciers progressed to as low a geologic horizon in the Waterloo district as it did in the Baraboo there would have been bluffs of Waterloo quartzite about as imposing as the Baraboo Bluffs.

[1] Warner, J. H., The Waterloo quartzite: Mining World, vol. 22, No. 16, p. 420, 1905.

[2] Van Hise, C. R., and Leith, C. K., The geology of the Lake Superior region: U. S. Geol. Survey Mon. 52, p. 364, 1911.

Lake Mills ledge.—About 4 miles south of the Hubbleton ledges in the SE. ¼ sec. 24 and the NE. ¼ sec. 25, T. 8 N., R. 13 E. (Waterloo Township), at the west edge of the broad marsh which borders Crawfish River, is a ledge of quartzite which may, for convenience, be called the Lake Mills ledge. This ledge, which rises about 25 feet above the marsh level, marks the top of the west slope of a broad preglacial valley underlying the marsh. A well about three-fourths of a mile east of the ledge is reported to have penetrated 100 feet of blue clay before reaching rock, which was sandstone. The exposure is about 80 rods long and 30 rods wide. As the rock also appears in a shallow well 80 rods west it is probable that a considerable area of quartzite thinly covered with drift lies between the exposed ledges and the high drift ridges to the west.

The rock composing the Lake Mills ledge is a dense quartzite, very dark purple to reddish purple in color, with reddish iron oxide in the cracks and seams. It is somewhat darker in color and coarser in texture than that of the Hubbleton ledges, some layers being almost black from the abundance of magnetite. Some layers are distinctly banded with darker and lighter tints. Microscopic sections show the same absence of clastic structure that is seen in sections from the other ledges. The quartz grains are larger on the average, and there is much less finely comminuted quartz between the larger grains. Iron oxide is present in somewhat larger quantity interstitially, but sericite bears about the same proportion to the other minerals as in the rock of the Hubbleton ledges. A section of the black rock which showed more clastic structure than any other section of the ledges examined is composed of rather fine angular to subangular grains of quartz of quite uniform size, not intricately intergrown in groups as in the other specimens, but with the individual grains distinct and largely surrounded by magnetite, giving the dark color noted above.

The bedding is not very clearly marked at this ledge. Seven readings on what appeared to be bedding plane gave the average strike as N. 50° W. and the dip as 42°–60° NE.

UNEXPOSED PRE-CAMBRIAN ROCKS.

Although having no particular connection with the discussion of the drift, it may be of interest to note here the elevations at which the pre-Cambrian rocks are known to underlie the Paleozoic formations at various points throughout the area under discussion.[1] The table on page 71 gives the locations at which these rocks have been reported in wells and the probable names of the immediately overlying Paleozoic formations. The elevations are approximate; most of them are taken from topographic maps of the United States Geological Survey.

The table shows that in several places (in Ripon, Springvale, and Lamartine townships, Fond du Lac County, and at Hartford and Rugby Junction in Washington County) pre-Cambrian rocks were found at the horizon of the St. Peter sandstone. This is the geologic horizon to which most of the several exposed knobs and ridges of quartzite and crystalline rocks noted above rise. From the elevations of these buried ledges and the depths to which neighboring wells have penetrated without reaching such rock it appears that at these places knobs or monadnocks similar to those exposed by the removal of the superincumbent sedimentary rocks in the region farther west must rise above the buried pre-Cambrian plain. In the other places the pre-Cambrian rock may represent the main basement plain of the Cambrian sediments. The lowest point to which a deep well has penetrated without passing entirely through the Cambrian sediments is 1,430 feet below the level of the sea at the Lake Park well in Milwaukee. The highest point on the Baraboo Bluffs at which quartzite is exposed is about 1,560 feet above the sea, so that the surface elevation of the pre-Cambrian wells has a known extreme range of at least 3,000 feet in the area under discussion. Were the Paleozoics throughout the area cut away down into the horizon of the Cambrian sandstones, as in the vicinity of the Baraboo ranges, many of these knobs or monadnocks would doubtless rise above the pre-Cambrian plain and it is quite possible that if only the glacial drift were removed the crests of several might be uncovered, as in the Waterloo ledges. There is thus a possibility that some of the crystalline bowlders and particularly the quartzites which are thought to be foreign to the area were really derived from some local ledges.

[1] The relations of the pre-Cambrian and Paleozoic formations are discussed at considerable length by Weidman, Samuel, Geology of north-central Wisconsin: Wisconsin Geol. and Nat. Hist. Survey Bull. 16, pp. 385–395, 1907.

It should be noted, however, that, as shown in the table, the cover of Paleozoic sediments thickens rapidly toward the east, and that the probability of such ledges having been exposed to glacial abrasion decreases in similar ratio. In fact, there is in the Waterloo district no evidence that any quartzite ledges, except those now exposed and those known to have been exposed to glacial abrasion because they are now covered only by drift, were the sources of any of the quartzite or igneous bowlders in the drift.

Pre-Cambrian rocks encountered in wells.

	Location.	Owner of well.	Depth to pre-Cambrian.	Elevation of pre-Cambrian above sea level.	Kind of rock.	Overlying rock.	Authority
			Feet.	*Feet.*			
1	Oshkosh	City or water company	785	− 35	"Granite"	Cambrian	Files of Wisconsin Geol. Survey.
2	....do	Old city well	680	850	Granite	....do	Geology of Wisconsin, vol. 2, p. 157, 1877.
3	Berlin	City	431	300	Rhyolite	....do	Weidman, Wisconsin Geol. and Nat. Hist. Survey Bull. 3, p. 33, 1898.
4	Ripon Township, SE. ¼ sec. 14.	H. A. Klitzke	101	870	"Granite"	St. Peter sandstone.	Owner.
5	Springvale Township, SE. ¼ sec. 14.	E. Wohlschlegel	140	800	....do	....do	Neighbor, somewhat doubtful.
6	Lamartine Township, SW. ¼ sec. 6.	Triangle Cheese Factory.	102	820	....do	....do	Member of the company.
7	Fond du Lac	City	1,030	−275	"Quartzite" (?)	Cambrian sandstone.	W. G. Kirchoffer in files of Wisconsin Geol. and Nat. Hist. Survey, and examination of samples.
8	Mount Calvary	Monastery	1,135	-75	"Quartzite"	....do	William Sealey, driller, Fond du Lac, Wis.
9	Elmore	Ulrich Legler	1,248	−268	"Granite"	....do	Do.
10	Waupun	City	(?)	(?)	....do	....do	Do.
11	Juneau	Insane Hospital	612	300	....do	....do	Supt. Eugene Derse, somewhat doubtful.
12	Hartford	City	541	435	"Quartzite"	St. Peter sandstone.	Timothy Foley, in files of Wisconsin Geol. Nat. Hist. Survey, and examination of samples by the writer.
13	Rugby Junction	Wisconsin Central Ry.	870	90	"Granite"	....do	F. M. Gray, driller, Milwaukee, Wis.
14	Menominee Falls	Wisconsin Sugar Co.	1,175 or 1,275	−340 or −440	"Red granite"	....do	F. M. Gray, driller, Milwaukee, Wis.
15	Oconomowoc, sec. 30	Montgomery Ward	1,300	−418	Very hard rock	Cambrian sandstone.	S. B. Geiger, driller, Chicago, Ill.
16	Watertown	City	1,060	−245	Dark gray crystalline rock.	....do	E. A. Mendenhall, driller, Watertown, Wis.
17	Portland Township, NW. ¼ sec. 2.	S. M. Austin	695	135	"Quartzite"	....do	Owner.
18	Portland Township, NE. ¼ sec. 29.	Knowlton	695	135	Very hard rock	....do	Do.
19	Jefferson Township, SE. ¼ sec. 10.	County Farm	990	−160	"Granite"	....do	Albert L. Hummel, driller, Fort Atkinson, Wis.
20	Delavan	Bradley Knitting Co.	1,679	−779	Quartzite	....do	F. T. Thwaites from examination of samples.
21	Kilbourn	City	465	463	"Archean rock"	....do	Geology of Wisconsin, vol. 2, p. 50, 1877.
22	Portage	Courthouse well	520	293	Quartz porphyry	....do	Wisconsin Geol. and Nat. Hist. Survey, from driller.
23	Madison	Capital Park	806	*a* 98	Dark-gray crystalline rock.	....do	Geology of Wisconsin, vol. 2, p. 50, 1877.
24	....do	City well No. 10	736	115	Diabase	....do	Pamphlet by John B. Heim, superintendent of waterworks, Madison, Wis.
25	....do	Chicago, Milwaukee & St. Paul Ry.	735	117	Dark crystalline rock.	....do	Geology of Wisconsin, vol. 2, p. 605, 1877.
26	Brodhead	City	1,030	−232	"Granite"	....do	F. M. Gray, driller, Milwaukee, Wis.

a Weidman says 70 feet.

PALEOZOIC FORMATIONS.

CAMBRIAN ROCKS (POTSDAM SANDSTONE OF WISCONSIN REPORTS).

CHARACTER AND DISTRIBUTION.

Overlying the eroded surface of the pre-Cambrian rocks throughout the area under discussion is a great body of sandstone, with some included limestone and shale, which has been generally known as the "Potsdam sandstone." A body of thin-bedded limestone with some associated shale, lying less than 100 feet below the base of the Lower Magnesian limestone, has been distinguished by the Wisconsin Geological Survey as the Mendota limestone from its typical exposure in the vicinity of Mendota Lake. Above this an upper sandstone set off from the main body of sandstone by the Mendota limestone has been designated the Madison sandstone by the Wisconsin Geological Survey from its having been extensively quarried for building in the vicinity of the city of Madison.

Throughout the greater part of the area southeast of Wisconsin and Fox rivers, the Cambrian sandstone is overlain by later

Paleozoic formations, and the distribution and thickness of the formation throughout this part of the area is known only from the records of numerous artesian wells. Along a sinuous line extending from northeast to southwest, as the southeast side of the Fox-Wisconsin Valley, the beveled edge of the lowest of the overlying formations, the Lower Magnesian limestone, terminates in a very irregular, much-dissected slope which is in many places a line of bluffs capped with the hard limestone and exhibiting, in the slope below, the Madison sandstone and Mendota limestone and the upper part of the underlying Cambrian sandstone. Numerous limestone-capped outliers border this dissected margin and a few more distant are evidence of the former greater extension of the capping formation. Emerging from beneath the limestone cover at the margin of the upland the sandstone extends over all the northwestern part of the area under discussion. Owing to its low dip and its considerable thickness the sandstone extends thence northward and northwestward over thousands of square miles of the area of the State, thinning gradually to an edge from beneath which the basement crystalline rocks emerge in the north-central part of the State. Through this sandstone project the several knobs of crystalline rocks already described (pp. 51–56) and the Baraboo quartzite range, about whose eastern end Wisconsin River swings in a broadly curving course.

The thicknesses of the Cambrian sandstone, including the Madison sandstone and Mendota limestone,[1] which are probably not developed everywhere and which, where present, are not always distinguishable in the records of drilling, are as follows at the places indicated, where the overlying Lower Magnesian limestone is still preserved:

Thicknesses of Cambrian sediments.

	Feet.
1. Fond du Lac, city well	430
2. Elmore, Legler well	206
3. Watertown, city well	738
4. Portland Township, sec. 29, Knowlton well	562
5. Brodhead, city well	805

1. W. G. Kirchoffer, files of Wisconsin Geol. Survey.
2. William Sealey, driller, Fond du Lac.
3. E. A. Mendenhall, driller, Watertown.
4. Owner.
5. Record, with samples by William Roantree and R. Boughton, Monroe; samples examined by writer and data from F. M. Gray, driller, Milwaukee.

[1] The Madison sandstone and Mendota limestone are regarded by Ulrich and Walcott as of post-Cambrian age.

Numerous other wells have penetrated as great or greater thicknesses of Cambrian sediments beneath the Lower Magnesian limestone without reaching the basal crystalline rocks. From the above and the following table, it will be seen that the known thicknesses range from about 200 feet to more than 950 feet.

Partial thicknesses of Cambrian sediments.

	Feet.
1. Waupun, city well	474
2. Juneau, city well	440
3. Jefferson, city well	582
4. Janesville, water company's well	846
5. Whitewater, city well	664
6. Palmyra, "oil" well	338
7. East Troy, Stephen Field well	965
8. Waukesha, city well	670
9. Elm Grove well	427
10. Milwaukee, Miller Brewery well	770
11. Racine, Horlick's Milk Factory well	945
12. Kenosha	600

1. W. F. Sealey, driller, Fond du Lac.
2. Examination of samples by the writer.
3. Record by driller.
4. Record by William Ruger at water company's office.
5. Record at State Normal School by William Inglebretson.
6. Geology of Wisconsin, vol. 2, p. 161, 1877.
7. Examination of samples preserved by Arthur Smith, Burlington.
8, 9, 10. F. M. Gray, driller, Milwaukee.
11. Wisconsin Geol. and Nat. Hist. Survey.
12. Dr. Hazleton.

Combining the section exposed below the base of the Mendota limestone in the bold bluff that rises from the north bank of Wisconsin River at the mouth of Honey Creek, in the town of Prairie du Sac, Sauk County, with that penetrated in drilling the artesian well at Capitol Park, Madison, Irving[2] obtained the following general section of the Cambrian rocks:

Generalized section of the Cambrian below the Mendota limestone.

	Feet.
3. Alternations of layers of purely siliceous white sand, ferruginous brown sand, yellowish calcareo-arenaceous layers, and layers of greensand; the calcareous bands increasing in amount of lime and in number toward the top, as do also the greensand layers	165
2. Entirely noncalcareous white and yellow sandstone; friable to indurated; fine to coarse grained	602
1. Red shale	10
	777

This serves fairly well for a generalized section below the base of the Mendota limestone in the region of Madison and of Wisconsin River. Under the cover of the higher Paleozoic rocks, however, variable thicknesses of red, brown, drab, bluish, and greenish shale are

[2] Irving, R. D., Geology of Wisconsin, vol. 2, p. 535, 1877.

intercalated in the sandstone where penetrated by many of the deep wells. In the excellent exposures afforded by the walls of The Dells at Kilbourn and neighboring gorges the sandstone shows a notable development of cross-bedding. (See, Pl. V, *B*, p. 32.)

To this structure and to the alternation of harder and softer layers and the consequent difference in the rates of disintegration under weathering and erosion is due much of the picturesque fluting of the sandstone walls of the gorges.

MENDOTA LIMESTONE AND MADISON SANDSTONE.[1]

In the vicinity of Madison and in the bluffs bordering Wisconsin River, 35 to 50 feet below the base of the Lower Magnesian limestone, there is developed a well-marked and persistent bed of yellow, thin-bedded limestone which has a thickness of about 30 feet. To this Irving[2] gave the name Mendota limestone from the large exposure at MacBrides [Farwells] Point on Lake Mendota. The 35 to 50 feet of sandstone between this limestone and the base of the overlying Lower Magnesian he designated the Madison sandstone from its yielding large quantities of excellent building stone in the vicinity of Madison. "These names," he says, "are not meant to be of anything more than local importance." The observations of Chamberlin, with which those of the writer agree, show that the Mendota is developed only locally as a limestone of any considerable thickness. Northeastward along the belt of outcrops the limestone disappears, and shale and shaly limestone are found at a horizon so nearly corresponding to that of the Mendota limestone that they have been correlated with the Mendota. E. O. Ulrich, however, maintains that instead of being Mendota this shale and shaly limestone belong to a horizon which he considers lower, that of the St. Lawrence formation of Minnesota.[3] Most of the deep wells bored through the overlying Paleozoic rocks and well down into the sandstone at many points throughout the area fail to encounter a limestone corresponding to the Mendota as developed near Madison. In its place, or at about the same horizon, there is frequently found a bed of red shale.

[1] These names are used in the sense in which they are used by the Wisconsin Geological Survey. Both the Madison sandstone and the Mendota limestone are considered post-Cambrian by Ulrich and Walcott.

[2] Irving, R. D., Geology of Wisconsin, vol. 2, p. 525, 1877.

[3] Personal communication, November, 1914.

The best exposures of the Mendota limestone seen by the writer are at Maple Bluff and Farwells Point, on the northeast shore of Lake Mendota, where the following succession was noted:

Section of Mendota limestone at Maple Bluff and Farwells Point.

	Ft.	in.
Thin, shelving purplish-buff layers of limestone	1	6
Three layers, buff-purple, blotched limestone	1	2
Buff, thin laminated, shelving limestone	5	5
Thin laminated, purple and buff, shaly limestone	1	0
Reddish-buff limestone	1	6
Heavy-bedded limestone with gently undulating lines of parting	3	3
Same	2	5
Same	5	10
Limestone containing sand grains	1–2	0
Talus over sandstone.		
	24	1

At one point the 5 foot 10 inch layer splits into 2 to 8 inch layers, and a layer of greensand occurs near the top.

The limestone layers break irregularly, but no crumpling or *Cryptozoon* structure was noted. In the bluff on Farwells Point, where 14 feet of Mendota limestone is exposed, some of the layers show crumpled laminæ and some of the blocks that have fallen on the beach are fossiliferous.

Below the limestone—that is, at the top of the lower sandstone—are beds which Ulrich has recently referred to the St. Lawrence.[4] It is his opinion that there is a hiatus between these beds and the overlying Mendota, with the Jordan sandstone absent. Ulrich also refers to the St. Lawrence the rock exposed in Miller's quarry, half a mile north of Pheasant Branch, which has heretofore been regarded as Mendota.

Section of St. Lawrence (?) formation at Maple Bluff.

	Ft.	in.
Buff calcareous sandstone with purple blotches and disseminated greensand grains	3	2
Beautifully cross-bedded greensand layer		9
Buff calcareous sandstone with disseminated sand grains	1	8

The thin-bedded reddish, purplish, and yellowish mottled rough-surfaced layers of the Mendota limestone are slightly exposed in the railway cuts west of the crossing near the agricultural buildings of the university, and also beneath the grand stand at the fair grounds. The heavier beds, underlying the purplish shaly layers, or what appear to correspond to them, are exposed not far west of the "Station 1 mile" post, in the Chicago, Milwaukee & St. Paul Railway cut west of the university, near the fourth ward school building on Brooks Street between Mound and Chandler streets near the west end of Lake Monona, and at A. Lillick's quarry in the NW. ¼ sec. 33, T. 8 N., R. 10 E. (Burke Township). At these places the rock is characterized by a peculiar structure which Irving called concretionary but which may be organic. At these places the layers are more or less distinctly laminated; and in cross section, as on joint faces, they appear to be crumpled in little folds a few inches in height and width. Where the surface of a layer is exposed it is seen to be uneven in consequence of small elliptical domes a few inches in dimensions, which are due to the curving laminæ seen in cross section. Where the tops of the domes have been worn off, the edges of the laminæ are arranged in concentric elliptical rings giving an appearance as of some organic structure. They resemble certain structures which have been described as stromatoporoid growths, but to which Hall gives the name *Cryptozoon*,[1] in describing their occurrence in the "Calciferous" of Saratoga County, N. Y. Winchell has described similar forms from the Shakopee dolomite at Cannon Falls, Northfield, and Mankato, Minn.,[2] and Dawson has discussed occurrences of *Cryptozoon* from the Ordovician and pre-Cambrian.[3]

The most southerly exposure of rock which has been correlated with the Mendota limestone within this area is at Mrs. Ida Barber's place on the west shore of Lake Kegonsa in sec. 26, T. 6 N., R. 10 E. (Dunn Township). Red shale, which is probably to be correlated with either the Mendota or St. Lawrence, was exposed in preglacial times in the slopes of the ancient Rock and Yahara valleys in the vicinity of Janesville, this being shown by the record of deep wells at the city waterworks, the fair grounds, and the Rock County poor farm, 3 miles north of the city. This shale may have contributed some of the reddish material found in the glacial drift west of these valleys.

[1] Hall, James, *Cryptozoon:* Thirty-sixth Regents Rept. on New York State Cabinet, pl. 6, 1883. Dr. E. O. Ulrich suggests that these may be calcareous algæ growths.

[2] Winchell, N. H., *Cryptozoon minnesotense:* Minnesota Geol. and Nat. Hist. Survey Fourteenth Ann. Rept., 1885.

[3] Dawson, Sir William, Note on *Cryptozoon* and other ancient fossils: Canadian Rec. Sci., vol. 7, pp. 203-217, 1896.

The Mendota limestone is rarely exposed within the area of the drift, and, where exposed, it appears only as a thin edge in the steep slope below the margin of the Lower Magnesian limestone. Its trace upon a map is an exceedingly irregular line drawn about the outliers and the reentrants and salients of the dissected margin of the upland. Northeastward along the line of outcrop the heavier limestone layers of the Mendota rarely outcrop. Some few thin, shaly, yellowish limestone layers are seen, but the red and purplish shaly layers (which Ulrich regards as St. Lawrence) are the most noticeable. Exposures occur near the mill at Cambria, in the railway cuts to the east, and in the ravines cutting the north slope of the valley to the west. The shales are exposed in the road on the slope a mile southwest of Kingston and in the south slope of Bartholomew Bluff, 2 miles west of Kingston. The shale rises above the water level in the south shore of Green Lake near W. T. Runal's Green Lake orchard and nursery, in sec. 6, T. 15 N., R. 13 E., in the Sugarloaf on the north shore of the lake, and in or near the roads in the south parts of secs. 31 and 33, T. 15 N., R. 12 E. (Princeton Township). At some places these arenaceous shales show abundant markings, as of fucoids or seaweeds, and at one or two places they show ripple marks in evidence of shallow water origin. Fragments of these shales and shaly limestones are frequently seen in the drift near or west of the line of outcrops.

The greater density and somewhat greater induration of the shales and limestones of these beds afford some protection to the underlying soft sandstone, so that a projecting shoulder in a bluff face often results from the recession of the face of the Madison sandstone above. One of the best instances of this is at Bartholomew Bluff west of Kingston where there is a cultivated terrace several rods in width on the top of the Mendota limestone, back of which rises the abrupt upper bluff of Madison sandstone capped with the Lower Magnesian limestone.

The relations of the Mendota limestone to the Baraboo quartzite ranges have a somewhat important bearing on the interpretation of the relations of the Cambrian and pre-Cambrian formations in this district. At one place north of the Baraboo Bluffs a slight remnant of what is thought to be the basal part of the Lower

Magnesian limestone was discovered 1,200 feet above sea level on Coon Bluff, in sec. 14, T. 13 N., R. 5 E. (Dellona Township). This shows the elevation of the top of the Cambrian north of the bluffs. At several places north of the west end of these bluffs the Mendota limestone was observed, viz, NW. ¼ sec. 2 and SE. ¼ sec. 11, T. 13 N., R. 4 E. (Westfield Township), and NW. ¼ and SE. ¼ sec. 30, T. 13 N., R. 5 E. (Dellona Township). The Mendota was also observed in the NW. ¼ sec. 26, T. 12 N., R. 5 E. (Excelsior Township) and the SE. ¼ sec. 6, T. 11 N., R. 5 E. (Freedom Township), between the north and south quartzite ranges. The exposures south of the bluffs are numerous, so that the Mendota horizon can be projected in cross sections of the district with considerable accuracy. Sections drawn to scale across the Baraboo basin from the outcrops noted north of the bluffs to those within and south of the bluffs show that the Mendota probably originally extended across the area with little variation in slope, being developed within the Baraboo basin as well as outside.

Two outcrops of limestone within the Baraboo basin correspond very nearly in elevations with those of the Mendota limestone as projected in the writer's cross sections. The first of these is at the old Eiky quarry, on the south slope of the north quartzite range, about a mile east of the Lower Narrows, beside the road ascending the slope in the NW. ¼ sec. 25, T. 12 N., R. 7 E. (Greenfield Township). Irving reported the following fossils from a collection made at this place by J. H. Eaton, and identified by R. P. Whitfield[1] as "certainly not lower than the Lower Magnesian" horizon:

Stromatopora sp. undet.	Holopea n. sp.
Orthis barabuensis?	Illænus antiquatus n. sp.
Metoptoma n. sp.	Dicellophalus barabuensis n. sp.
Maclurea sweezeyi n. sp.	

The fossils from Eiky's quarry are described under the following names by Whitfield:[2]

Leptæna barabuensis Whitfield.	Scævogyra elevata Whitfield.
Metoptoma barabuensis Whitfield.	Scævogyra obliqua Whitfield.
Metoptoma recurva Whitfield.	Dikellocephalus barabuensis Whitfield.
Metoptoma similis Whitfield.	Dikellocephalus eatoni Whitfield.
Metoptoma retrorsa n. sp.	Illænurus convexus Whitfield.
Scævogyra sweezeyi Whitfield.	

Whitfield states that a single specimen of a rather peculiar species of Stromatopora was found loose near the top of the quarry, but that marks of abrasion indicated that it might possibly have been derived from some other locality.

In the course of the examination of the Mendota limestone near Madison, the writer collected certain fossils from a small outcrop in a cut on the Chicago, Milwaukee & St. Paul Railway about a mile west of the university, on the north line of the NW. ¼ sec. 21, T. 7 N., R. 9 E. (Madison Township). This outcrop, which was near the chute used for loading rock from the adjacent quarries, was a dirty buff, uneven-bedded, irregular, loose-textured magnesian limestone. It occurs at about the same level as outcrops of limestone believed to belong to the Mendota, which is exposed in cuts at several places eastward to the crossing near the university. It is also at the same elevation as the hard yellow limestone reported by Irving as having been penetrated beneath the Madison sandstone in a near-by well[3] and referred to the Mendota. The fossils from it were examined by E. O. Ulrich, who identified *Archinacella similis* Whitfield, *Scævogyra elevata* Whitfield, *Billingsella barabuensis* Winchell, *Dikellocephalus eatoni* Whitfield, and *Hyolithus* n. sp. Ulrich states that these fossils leave scarcely a shadow of a doubt as to the exact equivalence of the rock near Madison to that in the Eiky quarry near Baraboo.

Fossil material was collected by the writer from loose blocks of limestone lying at the base of the bluff of Mendota limestone and Madison sandstone at McBrides Point, now Farwells Point, on the north shore of Lake Mendota. It was thought that the loose blocks were from the Mendota limestone above, though the fossils were not seen in the rock in place by the writer. Ulrich states that the material submitted to him from this locality agrees with that cited above as collected near Madison, and he concludes, therefore, that the rock at Eiky's old quarry in the Baraboo basin is also Mendota limestone.

Sandstone is exposed in the road on the slope both above and below the level of the limestone at Eiky's quarry. In sec. 30, T. 12 N., R. 8 E. (Caledonia Township), about a mile somewhat south of east from Eiky's quarry, rough-textured cherty limestone, like the typical Lower

[1] Geology of Wisconsin, vol. 2, p. 594, 1877.
[2] Idem, vol. 4, pp. 194-204, 1882.
[3] Idem, vol. 2, p. 604.

Magnesian limestone, is exposed at a barometric elevation of 40 to 50 feet above that at Eiky's quarry. About 80 rods southeast of the quarry, in sec. 25, T. 12 N., R. 7 E. (Greenfield Township), between the two outcrops of limestone, rises an abrupt cliff known as Pine Bluff. Rock is not exposed below a level 75 feet above the top of the limestone in the old Eiky quarry, but from this level a bluff of sandstone rises 135 feet or 1,320 feet above sea level. This sandstone Irving described as follows: [1]

> Its lower layers are medium-grained, very friable brownish banded sandstone, composed of very much rolled quartz grains; further up, some bands of bright-red sandstone are included, whilst near the summit are a number of rapidly alternating, red, white, and yellow bands of quite fine grained and saccharoidal sandstone, the whole thickness being 135 feet.

Similar sandstone, streaked and mottled, light colored, buff, brownish, and red, occurs as isolated hills rising above the Lower Magnesian upland plain in the southern part of T. 10 N., R. 9 E. (Arlington Township), 13 miles southeast of Pine Bluff. These are remnants of the St. Peter sandstone or of a sandstone more closely associated with the Lower Magnesian limestone. (See p. 82.)

The elevation of the sandstone in Pine Bluff corresponds with that of the St. Peter sandstone in the remnants noted in Arlington Township and with that forming the cliff on the upper part of Gibraltar Bluff in sec. 18, T. 10 N., R. 8 E. (Lodi Township).

From these facts it appears that the relations in the vicinity of Pine Bluff are as follows, viz: (1) The limestone at Eiky's quarry is Mendota, and the sandstone exposed higher up in the slope is probably Madison. (2) The Lower Magnesian limestone a mile southeast of Eiky's quarry is probably absent from Pine Bluff, or if present is thin and covered with talus. (3) The sandstone exposed in Pine Bluff is St. Peter sandstone or is part a sandstone which is more closely associated with the Lower Magnesian limestone and into which this limestone is, in places, seen to grade laterally within a distance of a few yards or rods.

The second outcrop of limestone to which reference was made above as occurring within the Baraboo is 2 to 3 miles southeast of Baraboo, at Wood's old quarry, in the SW. ¼ sec. 10, T. 11 N., R. 6 E. (Baraboo Township). This limestone is heavy bedded, porous in part, mottled buff and purplish, and carries some greensand. In texture it resembles that at Eiky's quarry. No fossils are reported to have been collected from this, but the writer noted the imprint of a coiled gastropod. Traces of *Cryptozoon*-like structure are also present in the rock at Wood's quarry. The rock does not carry chert, as does the Lower Magnesian limestone in sec. 30, T. 12 N., R. 8 E. (Caledonia Township); but Irving was inclined to consider it Lower Magnesian, particularly because he found in the bank of Skillet Creek, one-third mile north, beneath an intervening sandstone, at a level about 40 feet lower, an outcrop of 15 feet of yellowish rough-faced limestone closely resembling the Mendota limestone. The slight exposure seen by the writer was buff to purplish sandy limestone and calcareous sandy limestone, much like the usual Mendota beds. A. C. Trowbridge collected *Lingula* from these layers. The fact that the sandstone at Skillets Falls below the lower limestone beds does not resemble the usual infra-Mendota beds led Irving to ask, "Do the two limestone layers, with the intervening sandstone, form a patch lying on the eroded surface of much older sandstone represented by the indurated rock at the falls, as suggested in the case of the limestone of Eiky's quarry?" Ulrich regards the limestone at Wood's quarry as the same as that at Eiky's and as that noted in the railway cut near Madison and hence as Mendota, and he considers the shaly limestone in the creek bank below to be St. Lawrence and the intervening sandstone to be Jordan.[2]

Irving reported Cambrian fossils from large loose masses of sandstone on a projecting point of the north slope of the quartzite range, about 3 miles east of Wood's quarry, on the east line of the NE. ¼ sec. 13, T. 11 N., R. 6 E., at elevations of 560 feet above Lake Michigan (1,100 to 1,140 feet above the sea level) and 70 to 110 feet above the limestone in Wood's and Eiky's quarries.

If the rock in Wood's quarry is really below the Lower Magnesian horizon, as that at Eiky's quarry appears to be, then these fossiliferous blocks occur at a level corresponding to the base of the Lower Magnesian limestone or the top of the Madison sandstone as

[1] Geology of Wisconsin, vol. 2, p. 594, 1877.

[2] Personal communication, November, 1914.

projected in the writer's cross sections and not at an abnormally high level for Cambrian. Though the quarries are within the limit of the glacial advance the sandstone blocks are thought to be near the parent ledges. There is, however, a possibility that they were brought up from even lower levels by the ice, and as this is the only reported occurrence of fossils in the high-level sandstones their import is somewhat uncertain.

At numerous places on the slopes of the quartzite ranges sandstone occurs at various elevations ranging from those corresponding to the Cambrian sandstones up to levels corresponding to or even above those at which the Lower Magnesian limestone, if restored, would be in contact with the quartzite slopes. In most places the sandstone is not continuous from the lower to the highest levels, but in some places, as in the sandstone bluff flanking the south slope of the quartzite ridge 2 miles east of Devils Lake in the SE. ¼ sec. 20, T. 11 N., R. 7 E. (Merrimac Township), it extends continuously upward clear through the horizon of the Lower Magnesian limestone. There is thus some ground for thinking, as suggested by Irving, that the quartzite ranges were nearly or quite buried in a great sandstone formation, ong before the deposition of the Cambrian sands, and that this formation was largely dissected and removed by erosion before the incursion of the later Cambrian sea.

Certain observations of the writer favor this interpretation. In the NE. ¼ sec. 12, T. 11 N., R. 8 E. (Dekorra Township), the Cambrian sandstone is exposed down to the level of the water in the river, about 800 feet above sea level, affording a view of one of the lowest horizons of the Cambrian exposed within this area in the vicinity of the Baraboo Bluffs. There is here a 30-foot bluff of which the lower part is soft white fine-grained friable sandstone, topped by a 1-foot projecting ledge of buff calcareous cross-bedded sandstone. In this upper layer rounded disklike pebbles of calcareous sandstone, somewhat harder than the matrix, form a conglomerate. No pebbles of quartzite were noted with these. A similar conglomerate layer with pebbles of sandstone was seen in the SW. ¼ sec. 27, in the lowest sandstone exposed, about 5 feet above the road in a small ravine. Some similar pebbles were also seen in a layer about 10 feet higher up. In the NE. ¼ sec. 29 and the SE. ¼ sec. 20, T. 10 N., R. 8 E. (Lodi Township), a 2 to 2½ foot bed of similar conglomerate is exposed in the slopes of the small valley at a barometric elevation of 860 to 875 feet. In the west part of the lower south slope of Gibraltar Bluff, in the SE. ¼ sec. 13, T. 10 N., R. 7 E. (West Point Township), the same conglomerate is exposed at about the same level, or about 140 feet below the base of the Mendota limestone. These pebbles have the form of well-worn beach pebbles and, being of sandstone, indicate that the waves must have been eroding an indurated sandstone when the Cambrian sands were being deposited.[1] The fact that no quartzite pebbles were seen in this conglomerate, though such occur in the overlying sandstone in some of the same exposures, suggests that the quartzite ranges were largely enveloped in sandstone, and hence were not yielding quartzite pebbles to the beach. A. C. Trowbridge informed the writer that he had observed similar sandstone-pebble conglomerate at the corner 80 rods southeast of Wood's quarry in sec. 10, T. 11 N., R. 6 E. (Baraboo Township). This is 60 to 70 feet (barometric) lower than the limestone exposed in the quarry.

BASAL CONGLOMERATE.

Where the Cambrian sandstone is in contact with the Baraboo quartzite it usually includes a basal conglomerate of pebbles and bowlders of quartzite worn and rounded by wave action and embedded in sand. Very fine exposures of this conglomerate occur at several easily accessible points. At the Upper Narrows of Baraboo River it banks against the north and south slopes of the quartzite core of the ridge and extends in horizontal layers unconformably across the edges of the upturned quartzite beds. It has similar relations at the Lower Narrows. On the east bluff at Devils Lake, above the site of the old Cliff House, between 1,200 and 1,300 feet above sea level, about 15 feet of basal conglomerate overlies the low-dipping quartzite. The lower part is thickly crowded with pebbles and bowlders of quartzite ranging in

[1] Ulrich suggests that these may be intraformational tidal-flat pebbles produced by gentle washing of fragments of muddy sands which, while exposed at low tide, had dried out and hardened sufficiently to break up and withstand gentle washing by the returning tide.

size from a fraction of an inch to 5 feet or more in diameter. The conglomerate occurs in contact with the lower slope of the quartzite in the very picturesque ravines known as Parfreys and Dorwards glens, in the NW. ¼ sec. 23, T. 11 N., R. 7 E. (Merrimac Township), and the SW. ¼ sec. 7, T. 11 N., R. 8 E. (Caledonia Township), respectively. Small pebbles of quartzite have been noted in the sandstone as much as 5 or 6 miles south of the south range, and Irving [1] reports the occurrence of quartzite pebbles in Lower Magnesian limestone in an exposure on the prominent isolated bluff in the NE. ¼ sec. 20, T. 10 N., R. 7 E. (West Point Township).

Irving [2] suggests the following alternative explanations of the occurrence of the high-level sandstones on the quartzite ranges:

> It might be supposed that the wear of the quartzite ranges continued to produce sandstone and conglomerate beds during the growth of the limestone in the deeper water near by, but the suddenness of the transitions, the occurrence of Potsdam fossils in the sandstone, and the existence of the limestone layers close to and within the quartzite ranges appear great difficulties in the way of such an explanation. That the high-level sandstones represent really an older series, upon whose eroded upper surface rest the calcareous sandstone of the Potsdam, the Mendota, the Madison, and the Lower Magnesian, appears a more satisfactory explanation, but one which meets a considerable difficulty in the occurrence of upper Potsdam fossils in the high-level beds, and one which I am somewhat loath to advance, as too bold a generalization from the facts in hand. It is not impossible that the true explanation may lie in the supposition that during the deposition of the Potsdam series the quartzite ranges, being high islands and reefs in the ancient seas, received synchronous littoral depositions at high and abnormal altitudes, the sand and bowlders for these depositions coming from the wear of the quartzite itself.

In this connection it is interesting to note that similar basal conglomerate is found on the slope of the quartzite at one point in the Waterloo at an elevation corresponding to the Lower Magnesian limestone or the St. Peter sandstone. (See pp. 66 and 69.)

The basal conglomerate on the slopes of the eastern part of the Baraboo ranges was probably the source of many of the bowlders and pebbles of quartzite found in the drift, particularly south of the bluffs. The erosion and disintegration of this conglomerate on the slopes west of the limit of the ice advance gives rise in places to deposits which closely resemble heterogeneous glacial drift and some of which have been regarded as evidence of an earlier and greater extension of the ice beyond the line of the terminal moraine.[3] Close inspection of these deposits, however, failed to show the presence of a single piece of foreign material, so that they can not be regarded as deposits of glacial drift. In places the quartzite pebbles are so well rounded and assorted that, where the matrix has disintegrated or been removed, they may be mistaken for beach deposits of a Quaternary lake.

ORDOVICIAN ROCKS.

LOWER MAGNESIAN LIMESTONE.[4]

CHARACTER AND OCCURRENCE.

Conformably overlying the Cambrian sandstone is a body of dolomitic limestone to which D. D. Owen gave the name Lower Magnesian. It outcrops across the northwestern part of the area from northeast to southwest as an irregular belt and underlies the uplands east and south of the sandstone lowlands bordering Fox and Wisconsin rivers. Its margin was greatly dissected prior to the incursions of the glaciers, and remnants of it cap many abrupt salient ridges and isolated outliers which rise from the sandstone area. To the east and the south the dip carries it under the younger deposits within 5 to 15 miles from the margin. Prior to the deposition of the drift it was also exposed in the basins of Rock and Sugar rivers, where erosion had worn away the overlying beds. The location of the boundaries within the glaciated area is largely approximate, being based on records of wells, numerous small exposures, and general topographic conditions. In the mapping of this formation, as in that of each of the others, the delineation is based principally on the field observations of the writer and his assistants, supplemented in large measure from the maps of the Wisconsin Geological Survey.

[1] Irving, R. D., Geology of Wisconsin, vol. 2, p. 587, 1877.
[2] Idem, pp. 538-539.

[3] Weidman, Samuel, The Baraboo iron-bearing district of Wisconsin: Wisconsin Geol. and Nat. Hist. Survey Bull. 13, p. 101, 1904.
[4] Owing to the slight increase in knowledge of the rocks of this part of the Paleozoic section in southeastern Wisconsin since the publication of the early Wisconsin Survey classification this name, applied by that Survey, is used in this report. The name Prairie du Chien formation has been used in the Lancaster-Mineral Point quadrangle, which adjoins the southern part of the western boundary of this area, but its applicability over the whole State has been questioned.

The base of the formation is generally regular, but the upper surface is notably irregular, and the limestone varies in thickness from nothing to 250 feet. Within the belt of outcrop very much erosion has taken place since the removal of the superjacent beds, but even where these formations still cover this limestone the variation is quite as great. As noted below, it is not always possible to determine from the records of the wells just what material should be included in this formation. In places where the limestone is thin or absent there are shales and sandstones which can not everywhere be differentiated from the overlying and underlying formations. As nearly as can be determined, however, the following are the thicknesses of this formation at several points where the presence of the overlying formations shows that no removal of the deposits has taken place since Paleozoic time:

Thickness of Lower Magnesian limestone as penetrated by wells.

	Feet.
1. Mount Calvary monastery well, sandstone and limestone mixed	180
2. Fond du Lac, city well, red, brown, and pink shale and gray shale or limestone	125
3. Fond du Lac County insane hospital, limestone	15
4. Elmore, Ulrich Legler's well, limestone	240
5. Waupun, old city well on main street, chocolate and gray shale and "flinty rock"	15
6. Waupun, city well, at pump station, cherty gray limestone	17
7. Juneau, well at standpipe, red shale	35
8. Juneau, city well at pump station, red shale	90
9. Horicon, Campbell and Wilcox well, red shale	34
10. Oconomoc, city well, limestone	43
11. Watertown, city well, limestone	2
12. Watertown, Fred Miller's well, white, shaly limestone, including 3 feet of blue clay	21
13. Watertown, Ellis A. Mendenhall's well, sandy limestone	11
14. Portland Township, sec. 29, Knowlton's well, red shale 40 to 50 feet, cherty limestone 40 feet	80–90
15. Waterloo, Llewellyn's well, red sandstone 30 feet, red shale 40 feet, red limestone, sandy in lower part, 40 feet	110
16. Waterloo, city well, shaly rock 12 feet, sandstone, red limestone, white limestone 109 feet, red limestone 9 feet	130
17. Waterloo Iron Mining Co.'s shaft and drill hole, sec. 13, Medina Township, red, purplish, and buff shale and limestone 32 feet, cherty gray dolomite and sandstone 29 feet	61
18. Mequon, Ozaukee County, Chicago & Northwestern Railway well, red sandstone (possibly St. Peter or Cambrian)	100
19. Milwaukee, red "marl" 80 feet, limestone 170 feet	250
20. Milwaukee, Lake Park well, absent or all sandstone	141
21. Milwaukee, E. P. Allis's works well, absent or all sandstone or red "marl"	70
22. Milwaukee, Miller's brewery, red "marl"	60
23. Wauwatosa, city well, absent or all sandstone	?
24. Elm Grove, convent well, limestone	110
25. Waukesha, city well, limestone	80
26. Racine well, limestone	100
27. Racine, Lakeside well, limestone	160
28. Racine, Horlick Milk Co., gray dolomite 40 feet, dolomitic sandstone 20 feet, yellowish dolomite 30 feet	90
29. Kenosha, malt house well, limestone 80 feet, red "marl" (possibly Mendota) 20 feet	100
30. Western Union Junction (Corliss), Chicago, Milwaukee & St. Paul Railway well, limestone	141
31. Union Grove, village well, absent or all sandstone	?
32. East Troy, Stephen Field's well, bluish shale, buff, white, and gray limestone	64
33. Palmyra, "oil well," calciferous sand rock	62
34. Whitewater, city well, interbedded limestone, sandstone, and shale	60
34a. Mayville, Northwestern Iron Co. well, gray and red chert 4 feet, red shale and white sandstone 16 feet, blue shale 20 feet	40
35. Edgerton, Chicago, Milwaukee & St. Paul Railway well, brown sandstone (possibly St. Peter) 47 feet, red shale 123 feet	170
36. Janesville, Rock County poor farm, limestone	70
37. Rock Township, Riverside farm well, sec. 15, hard white limestone	80
38. Albany Township, sec. 30, William Smiley well, cherty limestone	30
39. Brodhead, city well, calcareous shale, sandstone, and limestone interbedded 54 feet, gray crystalline limestone 33 feet	87

1, 3, 4, 5. William Sealey, driller, Fond du Lac, Wis.
2. W. G. Kirchoffer, in files of Wisconsin Geol. Survey, grouping by the writer.
6, 8, 9, 17. Examination of samples of drillings by writer.
32. Same, preserved by Mr. Arthur Smith, Burlington, Wis.
33. Same, with data from the owner.
7. J. V. Roller, driller, Beaver Dam, Wis.
10. Wisconsin Univ. Bull., Eng. ser., vol. 3, p. 210, by W. G. Kirchoffer.
11, 12, 13. E. A. Mendenhall, driller, Watertown, Wis.
14, 15, 16. Joseph Scheberly, driller, Waterloo, Wis.
18. Paul Pankoff, Cleveland, Wis.
21. Data from Mr. Allis by Miss Harriett Merrill, Downer College.
19. Walter Burrows, in files of Wisconsin Geol. Survey.
20, 22, 23, 24, 25, 27, 29. F. M. Gray, driller, Milwaukee, Wis.
26, 30, 33. Geology of Wisconsin, vol. 2, pp. 161-163, 1877.
31. William Morgan, Union Grove, Wis., and examination of samples by writer.
34. Record by Edward Inglebretson at State Normal School, Whitewater, Wis.
35. A. R. Schultz, from Chicago, Milwaukee & St. Paul Ry. Co.
36, 37. E. Hindes, driller, Janesville, Wis.
39. Record by William Roantree and R. Boughton, Monroe, Wis., and examination of sample drillings by writer.
28, 34a. Wisconsin Geol. Survey.

The above data show the variations of thickness and composition which characterizes the formation where the superjacent deposits have not been removed by erosion. Not all these characters are well exhibited, however, in erosional outcrops. The shales and sandstones were so easily eroded after the protecting cover had been removed that, with few exceptions, only the magnesian limestone is seen. This limestone has quite distinctive characters and is usually readily distinguishable, whether as exposed ledges or as fragments in the glacial drift. It is principally of a dull-grayish or dirty-buff color and of very uneven crystalline texture, consisting of intermingled dense grayish compact limestone and portions where the dolomite crystals are but loosely aggregated. (See Pl. X, *B*.) This irregular texture results in the ledges having a very rough, ragged surface after long exposure to the weather, as the looser parts are much more readily dissolved out than the denser parts. A great deal of chert or flint, white, yellow, and reddish, is disseminated throughout the limestone, not in rounded nodules but in irregular patches. Portions of the rock are marked by many small irregular cavities into which silica-bearing waters have penetrated, lining the cavities with chalcedonic layers of quartz, upon which are superposed beautifully tinted quartz crystals. Where ledges have been so long exposed to the weather that the limestone has been partly dissolved away, the masses of chert and the siliceous linings of the cavities protrude, giving the rock an exceedingly ragged surface. Fragments of such rock were abundantly scattered over the surface (and are now largely gathered in piles along the fence lines) in those parts of the belt of outcrop where the formation has been much dissected by solution and erosion. These were particularly noticeable in portions of Green Lake and Columbia counties.

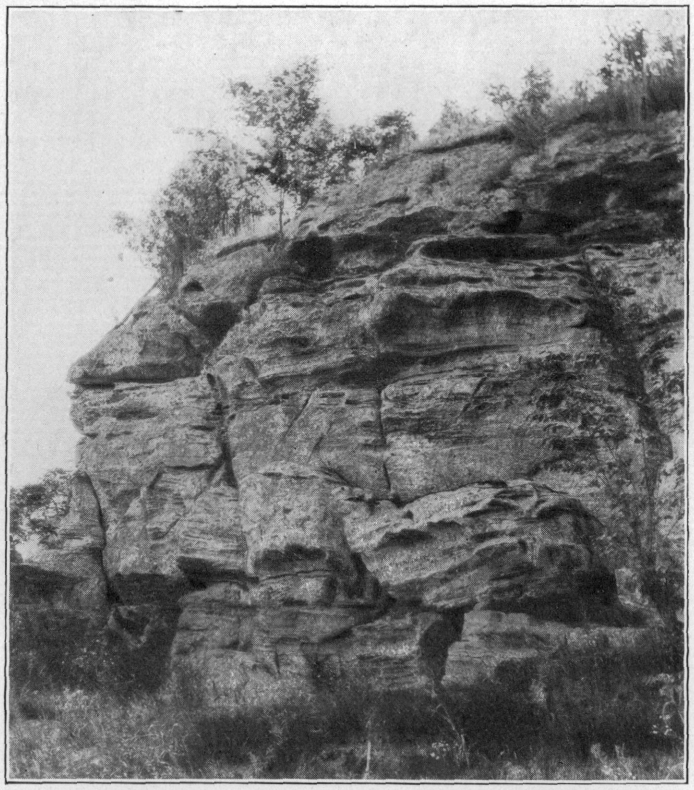
In the town of Westport, north of Lake Mendota, rock obtained from the formation for the construction of the Mendota insane hospital differed from that of other exposures, being of fine, even texture, and fairly regular bedding. In a section of 18 to 20 feet the rough-textured rock was noted only in a part of one layer near the middle of the section. At a few other places even-textured limestone was seen that evidently belonged to this formation but that even more closely resembled parts of the Trenton limestone, and probably could not be distinguished from it when incorporated in the drift.

A feature characteristic of the lower part of the formation is the presence of calcareous or siliceous oolite—that is, a rock composed of small rounded pellets, like fish eggs, about the size of a pinhead, closely set in a calcareous or siliceous matrix. The oolites when broken are seen under a magnifying glass to be composed of concentric layers enveloping a central sand grain. Some of the oolites are calcareous and others are siliceous, possibly as a later replacement by silica after removal by solution of the calcareous matter. The oolitic layers are particularly well developed in the vicinity of Madison, where they are exposed in the quarries, a section of one of which is given below:

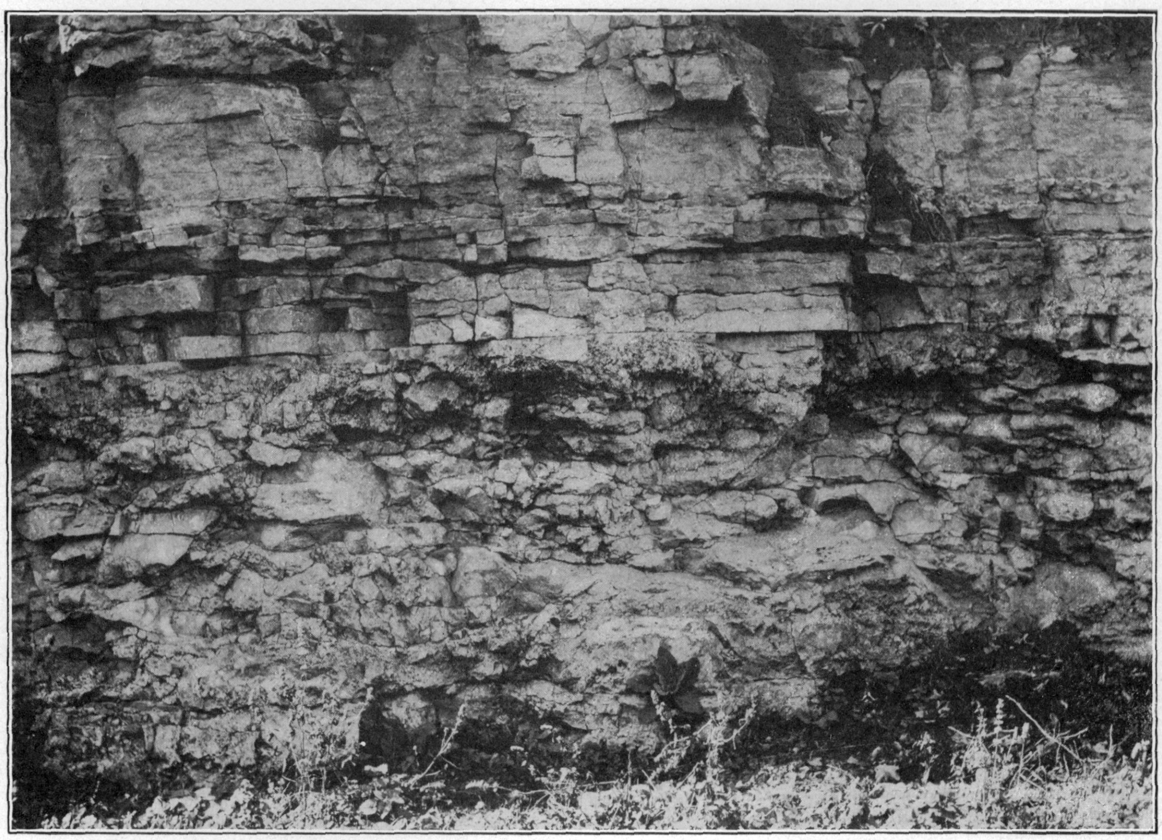
Section of Lower Magnesian limestone at city quarry, Madison (NW. ¼ sec. 21, T. 7 N., R. 9 E.)

	Ft.	in.
Weathered, rough textured, cherty dolomite		9
Same	1	9
Very cherty limestone, with thin curving laminæ and streaks of dense brownish chert with concentric structure, and some soft white chert	2	6
Dense gray limestone, with chert nodules; cherty and uneven at bottom	1	4
Mottled buff-grayish limestone	3	3
Same, rough textured	1	4
Fine-grained even-textured oolitic buff limestone	1	6
Rough-textured thickly laminated limestone	1	7
Uneven-textured loosely crystalline limestone	1	0
Very rough open-textured limestone	3	2
Irregular soft shaly buff and greenish limestone	1	3
Hard cherty oolitic limestone cavities lined with quartz crystals; some manganese dioxide	1	4
Oolitic limestone with chert bands	1	6
Fine dense buff limestone containing quartz grains	2	6
Even-textured oolitic limestone with undulating laminæ	1	7
Very fine grained even-textured buff limestone, with greenish streaks		6
Oolitic limestone containing angular fragments of dense buff limestone		7
Transition bed (buff sandstone 2 inches, white soft sandstone 3 inches, buff sandstone with thin layers of limestone 9 inches)	1	2
	27	7

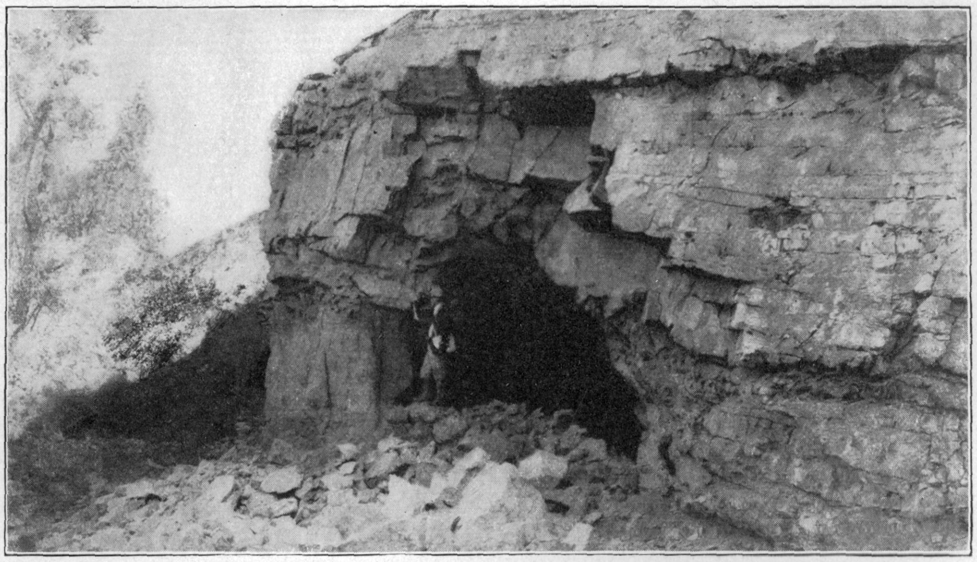
Another feature is the development of small domes in the bedding varying in size from a few inches to a few feet in diameter, giving structures such as those noted in the Mendota limestone (p. 74), some of which are probably related to the structures or growth known as Cryptozoa. Typical development of Cryptozoa seem to occur in the formation in some



A. ST. PETER SANDSTONE WEST OF BROWNTOWN, WIS., SHOWING RESULTS OF DIFFERENTIAL WEATHERING.

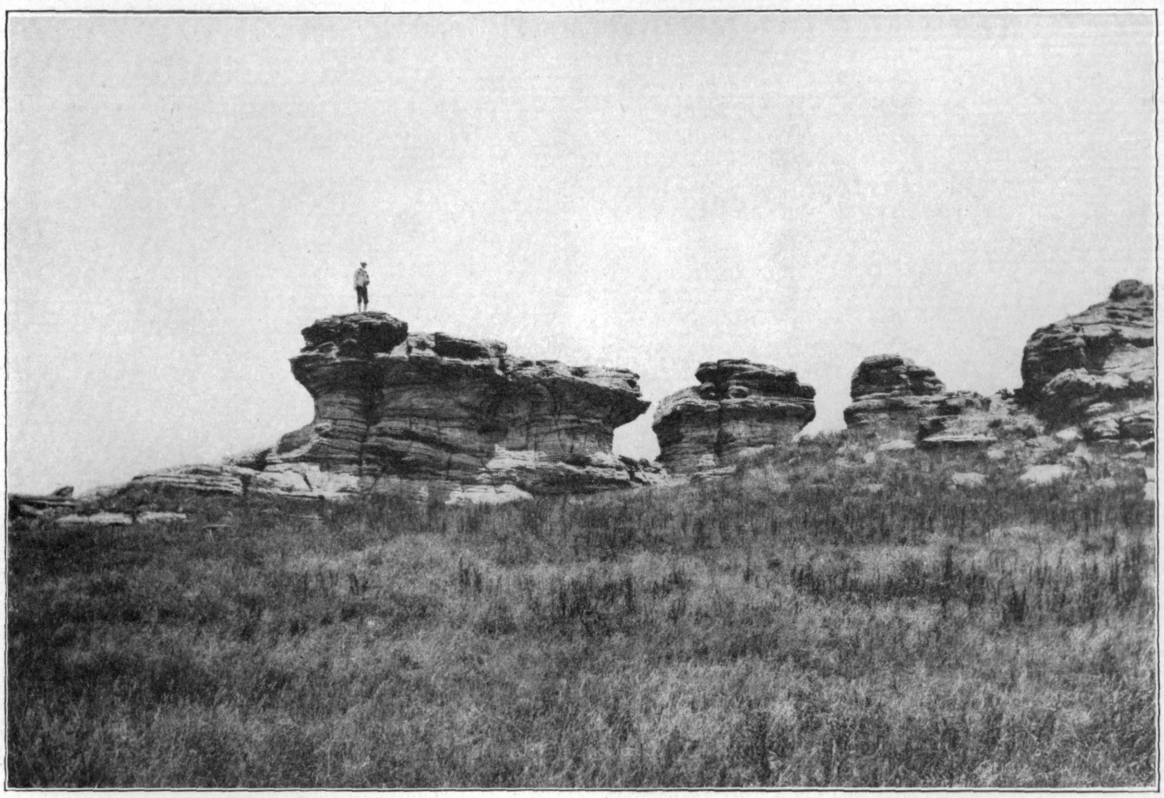


B. LOWER MAGNESIAN LIMESTONE EXPOSED HALF A MILE SOUTHWEST OF LAKE KEGONSA.



A. NIAGARA DOLOMITE UNCONFORMABLY OVERLYING "CLINTON" IRON ORE, NEAR NORTHWESTERN IRON CO. MINE, NEAR IRON RIDGE, DODGE COUNTY, WIS.

Photograph by G. J. Miller.



B. EROSION TOWERS OF ST. PETER SANDSTONE 4 MILES SOUTHEAST OF MONTICELLO, GREEN COUNTY, WIS., THE RESULT OF POST-ILLINOIAN WEATHERING.

places. Though they have not been seen in place in the rock, specimens have been found loose upon the surface. One of the best of these, 2 to 3 feet in diameter, was seen on the south line of the northwest quarter of sec. 2, T. 13 N., R. 12 E. (Randolph Township).

Not only is the rock of irregular crystalline texture but, as pointed out by Irving and Chamberlin,[1] it is characterized in places by brecciated layers, composed of angular fragments of limestone embedded in a limestone matrix, as though some layers after partial solidification were broken up as deposition continued. Bedded parts also grade into massive parts without regular lines of bedding, and there is often doming of the layers as though due to upheaval. Chamberlin showed that such disturbance as occurred must have taken place while yet deposition continued, as often the more regular layers continue up over the domes or mounds in such way as to indicate that the upheaval had not occurred subsequent to their deposition.

Fossil remains from the Lower Magnesian limestone are very meager, and it is probable that those which have been referred to this formation from Eiky's quarry in the Baraboo basin belong to a lower one.

It is reported that a small amount of galena was taken years ago from the hill in the N. ½ sec. 20, T. 6 N., R. 9 E. (Fitchburg Township). The rock exposed resembles Lower Magnesian limestone and is regarded as such by the writer.

The most northwesterly remnants of the Lower Magnesian limestone occur as cappings of sandstone bluffs in the SE. ¼ sec. 7 and the SW. ¼ sec. 3, T. 17 N., R. 8 E. (Springfield Township), Marquette County. At the more easterly of these two exposures, 2 miles west of Liberty Bluff station, an old quarry in the lower part of the west end of Lime Bluff exposes a great mass of limestone whose bedding dips into the hill at various angles up to nearly vertical, and which has evidently been disturbed. The rock at this exposure is fully 100 feet below the level of beds still in place on the upper east end of the bluff. The elevation of the contact of the limestone and the underlying sandstone was not determined on this bluff, but its elevation on the bluff in sec. 7, even allowing for a lowering of 100 feet or less in the distance of 2 to 2½ miles, shows that the exposed ledge has been dislocated, for the normal position of the base of the dolomite is well above the top of the west end of the bluff. It is probable that the rock exposed in the quarry was originally on top of the bluff, perhaps as a tower-like erosion remnant. This was either undermined by the crumbling of the underlying sandstone so that it slid down the west face of the bluff or it was dislocated by the glacier advancing westward and overriding the bluff. (See pp. 207–208.)

RELATIONS TO OVERLYING SANDSTONE.

Much of the unevenness of the upper surface of the limestone formation is due to its mound structure, but some of it was probably due to the deposits having emerged from beneath the sea, at least locally, and having been dissected by erosion and weathering. At numerous places in the vicinity of Albany, Green County, in the Sugar River valley, there is upon the surface of the limestone a bed of loose chert such as would be left as a residuum of long weathering and erosion. In a street cut just north of the schoolhouse at Albany, 3 to 5 feet or more of this loose chert was seen overlying a rounded and weathered surface of the limestone and underlying the undulating basal layers of sandstone, in whose lowest layer fragments of chert were included.

At very many places throughout the belt of outcrop where the surface of the limestone has not been eroded or stripped clean of the less consolidated overlying beds, there are small exposures of reddish, purplish, bluish, greenish, or white clayey shale or sandy shale at or near the contact between the limestone and the overlying sandstone. Most of the exposures are so poor that the relations can not be clearly seen, for where there is good exposure the shales, being soft and easily eroded, are readily washed away. Where penetrated by wells considerable thicknesses of the shale and associated sandstone are seen to occur. There is, however, one fairly good exposure of the limestone, shale, and sandstone in which the contact is not one of unconformity due to erosion but is an actual lateral gradation from the mound of limestone into the other deposits. This exposure is in a

[1] Irving, R. D., and Chamberlin, T. C., Geology of Wisconsin, vol. 2, pp. 268-285 and 547 et seq., 1877.

cut on the Illinois Central Railroad, 4 miles south of Belleville, Wis., in the NW. ¼ sec. 29, T. 4 N., R. 8 E. (Exeter Township), Green County. The section afforded by this cut is as follows:

Section in Illinois Central Railroad cut 4 miles south of Belleville, Wis.

	Feet.
Trenton limestone	0–5
St. Peter sandstone; massive buff sandstone, partly cross-bedded, dipping to south Brown to reddish sandstone Massive buff sandstone	20–30
Thin-bedded whitish sandstone and shaly sandstone, grading laterally into rough-textured, partly brecciated Lower Magnesian limestone forming a low mound [1]	5–15

Careful examination shows thin layers of sandstone intercalated between limestone layers and also the actual lateral gradation of limestone layers into sandstone within a few yards. It looks as though the mound of limestone might have been formed as a reef adjacent to which sand was being deposited, the calcareous and siliceous sediments being partly intermingled. Similar conditions appear to be exhibited in the railway cut just south of the station at Basco, Green County, but the relations are badly obscured by talus. These conditions raise some question as to whether all of the sandstone is really St. Peter or whether the lower part was not more closely associated in its deposition with the formation of the limestone. As already suggested (p. 76), it is possible that part of the sandstone of Pine Bluff in the Baraboo basin may be this sandstone, which is here so closely associated with the shale and Lower Magnesian limestone. Beside the shales, there are many occurrences of red sandstone either just below the St. Peter sandstone or within its lower part which the writer thinks may perhaps really belong with the Lower Magnesian formation. They are penetrated by many wells (see table, p. 79) but are rarely exposed. At what exposures there are, however, the sandstone differs from most of the St. Peter formation in that infiltration of silica-bearing waters has led to the rejuvenation of a large part of the quartz crystals which were deposited as rounded sand grains, so that on the water-worn surface of these grains have grown up the facets and pyramids of completed crystals. In consequence of this, fragments instead of having the dull surfaces of the ordinary sandstone, sparkle beautifully in the sunlight. One exposure of such red and yellow sandstone occurs south of the road in the north part of sec. 10, T. 9 N., R. 10 E. (Windsor Township), Dane County.

The relations of the St. Peter sandstone and the Trenton limestone to the uneven surface of the Lower Magnesian limestone are interesting and account for certain topographic features in the belt of outcrop where the upper limestone and the sandstone are largely removed by erosion. That there is a marked unconformity may be seen at many places. In consequence of this the St. Peter sandstone varies greatly in thickness. In many places, where it fills depressions in the surface of the Lower Magnesian, it thickens to 50 or 100 or more feet, and in near-by places, where it overlies elevations in the lower limestone, it is much thinner. In not a few places, the base of the Trenton limestone rests directly on top of hills of the Lower Magnesian, with little or no sandstone between. Furthermore, though not noted in exposures, the Lower Magnesian limestone is shown by well records to be in places entirely absent, either having graded into a sandstone or shale, or having been cut away by erosion prior to the deposition of the St. Peter, so that wells may penetrate hundreds of feet of continuous sandstone, or with only shale intercalated, below the base of the Trenton limestone. This is the case in the vicinity of Milwaukee, according to information furnished the writer by F. M. Gray, a driller of very wide experience.

The relations of the three formations are very well exhibited in the west slope of the Ceresco Valley at Ripon. Where the friable sandstone is thick, a steep slope or bluff results about the margin of the Trenton upland. Where it is thin or absent the slope developed on the limestones is much more gradual, and such locations are likely to be selected for the building of roads ascending the escarpment. From this it results that though the exposures afforded by grading many of these roads show little or no sandstone 50 or more feet of it may occur a fraction of a mile distant on either side. From

[1] Ulrich suggests that beds in the lower 5 to 15 feet of this exposure probably correspond to strata which in previous reports have been called New Richmond sandstone and Shakopee dolomite.

the vicinity of Ripon west and southwest to the vicinity of Mitchells Glen, in the SE. ¼ sec. 35, T. 16 N., R. 13 E. (Brooklyn Township), there is an escarpment 100 feet or more in height, and the glen itself is carved in sandstone fully 100 feet thick. Just a short distance east of this, however, and all about the margin of the Trenton southwestward to Little Green Lake, in southern Green Lake Township, the sandstone is thin or absent, and the escarpment becomes less abrupt, so much so that in places it is entirely buried in the coating of drift. In the bluff on the north shore of the lake the unconformable relations between the sandstone and the lower limestone are again exhibited. Similar relations are noted at many places southwestward through Columbia, Dane, and Green counties.

Where erosion has removed the Trenton capping and much of the sandstone has also been washed away, peculiar topographic and stratigraphic relations may result. The sandstone being so friable is readily removed from the undulating surface beneath, revealing a very ancient topography. In places, as near Albany, ledges of St. Peter sandstone outcrop about the base and slopes of Lower Magnesian hills. Again, valleys in the upper formations on being deepened may uncover hills of the lower limestone which, with continued deepening of the valleys, are left rising in the midst of the depressions. Such are the hills in the midst of the Black Earth Creek valley between Cross Plains and Middleton. Low swells thus located may have the form of drift hills and lead one to suspect the blocking of valleys by drift dams with consequent diversion of the streams. Similarly the billowy surface due to some of these rock swells simulates glacial morainal topography and, where near the border of the Driftless Area, may, unless scrutinized carefully, lead to wrong conclusions concerning the extension of the older drift, which is at best poorly developed in many places along this border. The assistance afforded to erosion by the exposure of the already uneven surface of this formation probably accounts in large measure for the intricate dissection of the formation in its belt of outcrop and the resulting irregular topography. Because of these relations many patches of St. Peter sandstone remaining within the belt of outcrop of the Lower Magnesian limestone are not shown on the map and can not be accurately delineated.

ST. PETER SANDSTONE.

Owing to the unconformity at its base and its great variation in thickness the St. Peter sandstone (so named by Owen[1] from St. Peter, now Minnesota, River) is not generally continuous over any very extensive area where the protecting cover of Trenton limestone has been removed. Even in the wider tracts so mapped it is probable that if the drift mantle were stripped off the formation would not be found continuous. As generally developed it consists of loosely aggregated, well-rounded quartz grains. Small amounts of iron oxide vary the color from pure white to buff or brownish, or even in places, as noted above, to yellow and bright red. In the outcrops near Ripon a beautiful salmon pink tint is often seen. In places the iron content is concentrated in the upper foot or so of the formation making a firm cement so that ferruginous fragments derived therefrom are frequently found upon the surface or incorporated in the drift. Much calcareous cementing material is also noted. In many places such parts give rise, on weathering, to rounded pellets or curiously grouped little balls of sandstone cemented with lime. Bluish or greenish clay material also colors the rock in places. Considerable red sandstone and associated shale occur at the base or in the lower part of the St. Peter sandstone, but part of this, at least, should probably be grouped with the underlying limestone. This is exposed in places but is not frequently seen. The evaporation of silica-bearing waters has, in places, caused deposition of silica in the interstices between the grains of the surficial parts of the rock and has caused the formation of a hard quartzitic crust, or casehardening, but in most places the formation is too friable to be used as building stone. Its principal economic use is for building sand, though it has been used to some extent in the manufacture of glass. On long exposure to the weather the rock crumbles to loose sand and has contributed large amounts of sand to the drift and to the soil in and near its belt of outcrop. The effects of differential weathering

[1] Owen, D. D., Preliminary report of progress of the Geological Survey of Wisconsin and Iowa up to Oct. 11, 1847: U. S. General Land Office Rept. for 1847, 30th Cong., 1st sess., S. Ex. Doc. 27, pp. 160–173, 1847.

of the harder and softer parts of the rock are marked. The bluff shown in Plate X, *A*, is beyond the limits of the glacial invasion and has probably been exposed to the weather for an exceedingly long time. The towers shown in Plates XI, *B*, and XVI, *A* (p. 140), are within the limits of the Illinoian glaciation and illustrate the amount of weathering since the disappearance of that ice sheet.

The thickness of the St. Peter sandstone varies greatly below a maximum limit of about 200 feet. Where thicknesses of continuous sandstone greater than this are penetrated below the base of the Trenton limestone it is probable that a part of the sandstone belongs with the Lower Magnesian formation, the limestone having given place locally to sandstone, or that this formation is absent in consequence of erosion prior to the deposition of the St. Peter and that the drill passes directly from the St. Peter to the Cambrian sandstone.[1]

Though much thinner than the Cambrian sandstone the St. Peter is continuous throughout the part of the State covered by the later limestones and extends far into neighboring States, being one of the most important sources of artesian water in all this region. The only fossils known from this formation in this part of Wisconsin are impressions of sea weeds (*Fucus*) and worm borings (*Scolithus*) reported by Chamberlin.[2]

TRENTON[3] LIMESTONE AND GALENA DOLOMITE.

Conformably overlying the surface of the St. Peter sandstone is a considerable body of magnesian limestone which, in Wisconsin, is generally differentiated into two parts, the Galena above and the Trenton limestone below. In the southern counties the Galena and Trenton, as differentiated by Chamberlin, are readily distinguished by their physical characteristics and fossil content. Farther north, however, through Dodge and Fond du Lac counties and into Winnebago County, the Galena is more like the Trenton and is not readily distinguished therefrom without a determination of the fossil content. Ulrich, indeed, thinks it not improbable that the Galena is really absent from this part of the area. Within the limits of glaciation the limestone is generally well covered with drift, being seen only locally in small quarries and natural exposures and nowhere in complete section. At the base of the Trenton a few feet of transitional deposits show the intermingling of sand with the initial calcareous deposits. Above lie a series of four sets of beds which, in many places, though not everywhere, are readily differentiable; and above these is the Galena.

The transition beds as observed in numerous places show a gradual change upward from siliceous sandstone through sandstone with some calcareous cement and magnesian limestone with disseminated quartz sand grains to magnesian limestone with little or no sand. In some places thin layers of limestone and of sandstone or shale are interbedded, the whole rarely exceeding 3 to 5 feet. No detailed examination of the characters of the Trenton and Galena limestones in most of that part of the area west of the Sugar River valley was made by the writer.

Chamberlin recognized the following subdivisions of the Trenton (from above downward) in eastern Wisconsin, each with the average thickness noted: Upper blue beds 35 feet, upper buff beds 55 feet, lower blue beds 25 feet, and lower buff beds 25 feet. The buff beds, which are not everywhere buff in color but in places are in part at least bluish gray, are generally of fairly even grain, uniform, fine, crystalline, dense texture, regularly bedded in layers about 4 to 14 inches thick. Porous layers occur locally, and zones of chert nodules were noted in the upper buff beds. The rock is highly fossiliferous, the forms being preserved usually as casts or impressions. The original color appears to have been bluish gray, but this is largely oxidized to buff; and many of the thicker layers are still bluish gray in the middle, though grading to buff at the top and bottom of the beds. This rock is wholly different in all these characteristics from all phases of the Lower Magnesian limestone except the most even and fine grained and may usually be readily identified even as small fragments in the drift.

[1] The well of the Bradley Knitting Co., Delavan, Wis., drilled in 1915, penetrated gray sandstone 130 ? feet, blue shale and buff to pink sandy shale 135 ? feet, and layers of white and buff sandstone, pink shale, and white chert 45 feet, a total of 310 feet, regarded by F. T. Thwaites as probably belonging to the St. Peter sandstone, with no deposits referred to the Lower Magnesian.

[2] Geology of Wisconsin, vol. 2, p. 288, 1877.

[3] Owing to the fact that the increase in knowledge of the rocks of this part of the Paleozoic section in southeastern Wisconsin since the publication of the early Wisconsin Survey classification has been slight, the name applied by that Survey is used in this report. In the Lancaster-Mineral Point folio (No. 145, U. S. Geol. Survey) the name Platteville has been applied to this limestone.

The blue beds contain much more argillaceous matter and are largely thin bedded and shaly, and the layers are in many places separated by bluish or greenish clayey partings. These beds are highly fossiliferous and in many places are crowded with silicified fossils, especially with corals, bryozoans, and small brachiopods.

Where exposed in unweathered quarry faces the upper blue beds are in places compacted into heavier layers, through which run thin dark lines of parting along which the rock splits into thin layers with uneven surfaces; and where long exposed to the weather these lines of parting open up so that the rock appears thin and shaly. In some of the exposures the character of the rock gradually changes from the shaly blue layers to the buff Galena above; at others the line of demarcation is sharp, though no indication of a break in the continuity of deposition has been noted by the writer.

In thickness the Trenton limestone averages about 125 feet, but its full thickness is rarely if ever seen in a single exposure, and it is not usually possible to distinguish it from Galena in such records and samples as are preserved from the drilling of wells. In the southwestern part of the area its thickness is in many places less than 100 feet, rarely as low as 60 feet.

In the northern counties the Galena and Trenton limestones underlie the drift in a broad belt which varies in width from 15 to 20 miles as far south as Dane and Jefferson counties; in the southern counties, Walworth, Rock, Green, and Lafayette, the two spread over three-fifths of the width of the area under discussion, including nearly the whole of Rock, Sugar, and Pecatonica river basins and extending thence westward. Over considerable tracts bordering these streams these limestones were removed by erosion prior to the incursion of the glaciers, disclosing the underlying formations. Through most of this belt east of Rock River and on the uplands west of Sugar River much of the Galena yet remains, but elsewhere it is found only on the crests of the highest ridges and from some of these even it is absent.

In the Driftless Area and the area of the older drift and northward through Jefferson County the Galena can usually be readily distinguished from the Trenton limestone by its physical characters alone. North of this latitude the writer has found it difficult to discriminate the two without the aid of fossil determinations. As seen in the southern counties the Galena is a buff, rather uneven textured, earthy to finely crystalline, magnesian limestone, regularly bedded in layers about 4 to 14 inches thick. It is generally porous, in places showing small irregular cavities an inch or so in diameter, and carries much white chert in rounded nodules distributed along more or less definite horizons. Where long exposed to the weather, as it has been in many places, especially in the area of the older drift and in the Driftless Area, its softer and looser-textured parts have been dissolved and have crumbled away, leaving very rough, cavernous, rotten-looking ledges that differ strikingly from the bluish, shaly, upper layers of the underlying Trenton. The more solid, thick beds in some of the fresh quarry faces have a bluish-gray tint.

The removal of this limestone by solution and from the breaking up of the rounded nodules it contains leaves a great quantity of angular chert in the soil, particularly in the Driftless Area and on the crests of the ridges west of Rock River, where the drift is thin in the area of the earlier glaciation. The limestone carries many fossils, one of the most common of which is *Receptaculites*, popularly known as the "sunflower coral" because of the resemblance the pores on its disklike surface bear to the seeds in the center of a sunflower.

North of Jefferson County the rock, as seen in most of the exposures, is not so irregularly textured and is bluish gray instead of buff, more closely resembling the heavier bluish layers of the Trenton. It is regularly bedded in 2 to 10 inch layers with infrequent fractures so that large flagstones are readily taken out. The beautifully glaciated upper layers have been extensively used in Waupun for sidewalks. In this part of the area the Galena formed the floor of the broad monoclinal trough along which advanced the axial flow of the Green Bay Glacier and it probably underwent very vigorous abrasion.

The Trenton and Galena limestones have made very large contributions to the drift. Very many of the hundreds of analyses made by the counting and sorting of pebbles of the drift show that they furnish 80 to 90 per cent of the coarser easily recognizable material.

As these pebbles are not the residuum from long preglacial weathering of the limestones, but are mostly sound, freshly abraded fragments, their occurrence in the drift with so much freshly ground calcareous rock flour, largely from the same source, probably means that considerable thicknesses of solid limestone were removed during the successive advances of the glaciers.

Many wells show a thickness of 150 to 200 feet for the combined Galena and Trenton formations; a number have been reported as penetrating them for 200 to 250 feet, and a few for greater distances. W. H. Pellington, of Sharon, Walworth County, stated that the village well at that place penetrated 335 feet of Galena and Trenton limestone, which is very near the maximum for the rock within the area. The thicknesses shown by wells drilled within the belt to the east, where later formations yet remain, range from 150 to 350 feet, the average of 26 measurements being 260 feet.

MAQUOKETA SHALE (CINCINNATI SHALE OF EARLY WISCONSIN REPORTS).

Overlying the Galena dolomite is a shale which was called "Cincinnati" shale in the earlier Wisconsin reports. It is stated by Ulrich that its limits do not correspond with those of the Cincinnatian series. The same unit has been named the Maquoketa shale, from its development in the region of Maquoketa, Iowa, and this name has been applied in the Lancaster-Mineral Point folio.[1]

The formation, which consists for the most part, so far as known, of soft bluish and greenish clay shale with some intercalated magnesian limestone layers, is so little indurated that it is readily removed by erosion where the capping of Niagara dolomite no longer remains. In consequence most of the shale was probably stripped off the surface of the Galena dolomite by erosion prior to the advent of the glaciers, and much of what remained was doubtless incorporated in the drift during the glacial advance. Removal of the drift would thus expose only the edge of the formation in the slopes below the Niagara escarpment with a few outlying thin patches. At present only very small exposures of the uppermost part of the shale remain within this area. It is thought to overlie the Galena dolomite conformably, but the contact has nowhere been seen by the writer.

[1] U. S. Geol. Survey Geol. Atlas, Lancaster-Mineral Point folio (No. 145), p. 7, 1907.

Seven miles north of the north limit of the area described at the Stockbridge brick works on the east shore of Lake Winnebago 30 or 40 feet of the shale is exposed in a clay pit, where it is being excavated for the manufacture of brick. The deposit is principally bluish-gray clay shale, which is so soft as to be excavated with a plow and scrapers drawn by horses. Two hard highly fossiliferous layers, one 6 to 8 inches thick, the other 12 to 14 inches thick, are exposed in the upper part of the excavation about 25 feet above the level of the lake. The slope above is grassed over, but slight exposures of the shale occur in gulleys nearly up to the base of the Niagara dolomite ledge which caps the slope nearly 165 feet above the lake. The general character of the formation in the area under discussion is known from the descriptions of numerous drillers. In his description of the formation[2] Chamberlin states that a shaft was sunk in it in search of coal in sec. 24, T. 7 N., R. 18 E. (Delafield Township), south of Lake Pewaukee. "The shaft and boring together reached a depth of 50 feet and showed an alternating succession of blue shale and gray, yellow, and blue limestone, associated with some crystallized quartz, and with considerable iron pyrites." Both Chamberlin and the writer collected numerous fossils from the surface of the dump from this old opening.

At the mine of the Northwestern Iron Co., 2½ miles north of Iron Ridge station, sec. 12, T. 12 N., R. 16 E. (Hubbard Township), the top of the shale forms the floor of the open-cut mine. Here the lower face of the uppermost shale layer is covered with a very remarkable network of varied and curious forms, which may be of either organic or concretionary origin.

In the drift in the vicinity of Eagle Chamberlin found material from this formation which he described as follows:[2]

> In this vicinity the drift contains many blocks of a fine-grained dark clay shale, and a lighter-colored olivaceous-gray arenaceous rock, having a somewhat shaly structure. The two kinds are not uncommonly united in one bowlder, but the former soon disintegrates on exposure. The slaty portion also contains many comminuted fragments of *Lingula*, provisionally identified as *Lingula*

[2] Geology of Wisconsin, vol. 2, pp. 316-318, 1877.

maquoketa, and of indistinct graptolitic remains, similar to *Climacograptus*. As this is a very soft rock, and the blocks are little worn and are essentially confined to this vicinity, where the glacial moraine crosses the Cincinnati belt, it is safe to conclude that it forms one of the members of the Cincinnati group at this point.

The material composing the bulk of this formation when exposed and wet forms an exceedingly tenacious clay. Well drillers find it difficult to penetrate because of the manner in which it sticks to the drill. It is believed that the shale yielded considerable amounts of this clay to the glaciers, especially to the Green Bay Glacier, which advanced southward directly along the trough in whose bottom and east side the shale must have been exposed, and that this ingredient was an important factor in the development of the drumlins of the area. Though probably present in the drift in considerable amounts, little of it is recognizable, most of it going to help form the clayey matrix of the till. Shaly pieces and fragments of thin silicified fossiliferous layers have been noted but not in abundance.

The known thicknesses of the shale beneath the Niagara dolomite range from 40 to 365 feet, the average of 36 measurements being 185 feet. Only three measurements were over 300 feet. William Sealey, well driller, Fond du Lac, Wis., informed the writer that in drilling the well at the Mount Calvary Monastery, sec. 29, T. 16 N., R. 18 E. (Marshfield Township), Fond du Lac County, 365 feet of shale were penetrated between the base of the Niagara dolomite and the Galena. Allan McElroy, well driller, Waupun, Wis., stated that his drill passed through 333 feet of shale belonging to this horizon in drilling a well for A. J. Parratt, sec. 33, T. 14 N., R. 16 E. (Oakfield Township), Fond du Lac County, and Julius C. Green, well driller, Beloit, Wis., informed the writer that in the well at the Spring Creek creamery south of Lake Geneva, in sec. 33, T. 1 N., R. 17 E. (Linn Township), Walworth County, his drill penetrated about 300 feet into the shale without passing entirely through it.

On the other hand, the thicknesses of shale in several wells were much below the average, being but 40 feet at the Wisconsin Sugar Co. factory in Menominee Falls, Waukesha County,[1] 80 feet at the Waukesha County poor farm north of Waukesha,[2] 60 feet at F. A. Koepsell's place in sec. 5, T. 11 N., R. 17 E. (Herman Township), Dodge County,[3] and 52 feet at Union Grove, Racine County.[4] Whether this inequality is due to conditions of original deposition or to unconformity either at the base or top of the shale, the writer is unable to state, although Chamberlin, as noted below, found a slight unconformity between the shale and the overlying iron ore.

The abruptness of the escarpment, which would have a height of 300 to 500 feet or more if the drift filling in the valley below were removed, is largely due to the slight induration of the shale, which was readily removed, while the margin of the dolomite above was kept abrupt by the breaking off and sliding down of great masses of rock. The effect of creep of such masses on the surface of the slippery wet clay is well exhibited at many places along the crest of the escarpment.

The occurrence in the southwestern part of the area of remnants of the Maquoketa shale and the Niagara dolomite in elevations known as the Blue Mounds, in secs. 5 and 6, T. 6 N., R. 6 E. (Blue Mounds Township), Dane County, and in sec. 1, T. 6 N., R. 5 E. (Brigham Township), Iowa County, is evidence of the considerably greater former extension of these deposits in the southern part of the State. Other remnants occur farther southwest in the Mineral Point quadrangle; and the shale has also been mapped near the State line in the town of Gratiot at the southwest corner of the area under discussion. As no detailed examination of this immediate vicinity has been made by the writer, its present extension within the bounds of the area has not been determined. It is thus practically certain that the shale once extended continuously over more or less of the southwestern part of the area. Though it can not be asserted that the shale was continuous from west to east across northern Illinois and southern Wisconsin such may not improbably have been the case. By far the greater part of such former extension of the shale was probably removed prior to the incursion of the glaciers.

[1] P. S. Seigman, driller, Menominee Falls, Wis.

[2] Mr. Bennett, driller, Pewaukee, Wis.

[3] William Speeling, driller, Iron Ridge, Wis.

[4] William Morgan, driller, Union Grove, Wis.

SILURIAN ROCKS.

"CLINTON" IRON ORE.

Overlying the Maquoketa shale in places there is a bed of iron ore which Chamberlin considered as representing the Clinton ore of New York. Hall[1] regarded part of the dolomite overlying the iron ore as probably belonging to the Clinton formation but did not find it readily differentiable from the Niagara dolomite above. Chamberlin,[2] however, saw no good reason for the separation of the lower and higher parts of the dolomite. He cites a slight unconformity with the underlying shale as a reason for not grouping the iron beds with the shale formation.

The iron ore is exposed below the Niagara dolomite in the SW. ¼ sec. 12 and the W. ½ sec. 13, T. 11 N., R. 16 E. (Hubbard Township), Dodge County. At the Northwestern Iron Co.'s mine in the SW. ¼ sec. 12, the ore bed was well exposed at the time of the writer's visit in 1909, the overlying 10 to 20 feet of Niagara dolomite having been stripped off several square rods of the slightly undulating surface of the ore. The thickness of ore exposed varied from 15 to 25 feet and it was said that a test drill hole a short distance back from the bluff face showed a maximum thickness of 28 feet of ore. At the bottom of the ore bed and the top of the shale there is a hard purplish layer, partly indurated shale and partly ore. Reference is made above to the remarkable organic or concretionary structures on the lower side of this layer. Just above this the ore appears to be conglomeratic, containing pebble-like nodules of soft ocherous rock. With the exception of the uppermost foot or two, which is of hard purplish-red hematite, the bed consists of soft reddish-brown lenticular disks averaging about one twenty-fifth of an inch in diameter and resembling flaxseed, embedded in a soft ferruginous matrix. Cross sections show that these disks are made up of concentric layers. The superintendent of this mine, B. W. Vallat, stated that the bed worked in 1909 (when visited by the writer) carried about 51 per cent of iron, the lowest average being 45 per cent, and the hard upper layer carrying 60 to 61 per cent. The average silica is about 7 per cent, phosphorus 1.2 per cent, lime 5 to 6 per cent, and magnesia 4 per cent. Old workings expose the ore bed more or less continuously southward for about a mile, and borings are said to show the presence of ore for a mile or more northeastward, but to the north and southeast it appears to pinch out, though other masses unknown to the writer may have been disclosed by test borings. The bed seems not to be continuous for long distances, there being no other exposure along the escarpment within this area.

There are two interpretations of such a condition, one being that the ore accumulated in local basins in the surface of the underlying shale and was thus originally in lenticular masses and was so covered by the deposition of the overlying dolomite; in this case the upper surface of the ore would not rise above the surrounding surface of the shale. The other interpretation is that the beds were somewhat more extensive, whether accumulated thus in basins in the shale or not, and that they were exposed to erosion before the overlying rock was formed, their present small extent thus being due to erosional unconformity. At one point just south of the mine the ore has been worked out, and the exposure shows the limestone ore bed, which is about 15 feet in thickness, pinching out a little back of the bluff face. (See Pl. XI, *A*, p. 81.) At the right of the opening the roof of dolomite drops down in a contact wall which lay against the edge of the ore that has been excavated. The lower limestone layers are very irregular and ocherous from the intermixture of ore with the calcareous sediments; higher up the layers turn up slightly against the slope; and above, the beds rise over the surface of the ore. This appears to be not a relation normal to continuous conformable deposition but an erosional unconformity. The present small extent and local character of the ore deposits appear thus, to some degree at least, to be due to an interval during which the bed was exposed to erosion prior to the submergence which resulted in the deposition of the overlying dolomite. It may also be true that to erosion occurring during this interval of exposure is due the considerable variation in thickness of Maquoketa shale. (See p. 87.)

At one point where but 6 feet of dolomite remained over the ore bed at the time of the

[1] Hall, James, and Whitney, J. D., Report on the geological survey of Wisconsin, vol. 1, pp. 57-59, 1862.

[2] Chamberlin, T. C., Geology of Wisconsin, vol. 2, pp. 327-328, 1877.

glacial advance, the dolomite is broken up and the ore to a depth of 2 or 3 feet is much disturbed as a result of the ice push.

Numerous wells in the towns of Herman and Rubicon, north of Rubicon Creek, and in the vicinity of Hartford are reported to have encountered red ocherous material at the base of the Niagara dolomite. At Kissel's quarry, in the southeastern part of Hartford village, tilted ledges of dolomite were exposed with glacial drift thrust into and beneath them, as though the margin of the dolomite at the top of a preglacial slope was forced upward by the push of the glacier. Here more or less ocherous material occurs with the dolomite, either originally overlying it or thrust into its present position, and is also commingled with the drift.

About 8 miles southwest of Hartford, in the SE. ¼ sec. 22, T. 9 N., R. 17 E. (Ashippun Township), the well at John Mason's place opposite the Episcopal Church is said to have penetrated the following deposits:

Log of John Mason's well, SE. ¼ sec. 22, T. 9 N., R. 17 E. (Ashippun Township).

	Feet.
Drift	2
Niagara dolomite	7 or 8
Soft red rock ("Clinton" iron ore)	10 or 12
Maquoketa shale	66
	86

Fragments of both the hard and soft ore such as occur at Iron Ridge were found on the slope just north of the house, though the bed was not actually exposed. Soft red material is reported to have been encountered in some of the deeper wells elsewhere in the towns of Ashippun, Delafield, and Germantown.

In the NW. ¼ sec. 21, T. 5 N., R. 17 E. (Eagle Township), considerable iron has been deposited by a spring issuing from the slope near the level of the top of the Maquoketa shale, and it may be possible that a buried deposit belonging to this horizon is near at hand.

A recent discovery of the ore bed is discussed as follows by F. T. Thwaites:[1]

Recently samples from a well drilled southwest of Manitowoc for the Northern Grain Co. came under the writer's observation, being presented to the museum of the University of Wisconsin by the United States Geological Survey. The character of the "Clinton" ore there penetrated had heretofore escaped observation.[2] The succession is as follows:

Record of well southwest of Manitowoc, Wis.

	Thickness.	Depth.
	Feet.	*Feet.*
Clay and sand	90	90
Niagara dolomite: hard, gray to brownish dolomite, softer at base. Water found down to 763 feet. Yield, 350 gallons a minute, with casing at 400 feet	735	825
"Clinton" ore; soft dark-red calcareous oolitic hematite	30	855
Same, but oolitic texture is less marked, so is probably more clayey	25	880
Maquoketa ("Cincinnati") shale.		

An assay[3] of the samples from the "Clinton" ore gave iron 33.98 per cent and phosphorus 1.041 per cent, but this result should be received with caution on account of the method of taking the samples, which might result in concentrating the heavy minerals. Nevertheless, it is clear that at least the upper 30 feet of the deposit is ore of promising character. Nothing is known of the lateral extent of the ore, as wells of sufficient depth to reach it are not at all common in the vicinity. No ore is reported from the deep well at Two Rivers, 8 miles to the northeast.

Red beds appear to have a wide though discontinuous distribution in parts of Racine, Kenosha, and eastern Walworth counties. Wells in 13 different townships were reported to the writer as having penetrated soft red deposits 1 to 50 feet thick that lay at the base or in the lower part of dolomite generally referred to the Niagara formation. The color is usually dark red, though the material from a 16-foot bed penetrated by Mr. Haley's well 1½ miles southeast of Franksville, Racine County, was said to look like yellow paint.

These red beds appear to be confined to the lower part of the formation above the shale. In places they immediately overlie the shale, occupying a position corresponding to the exposures of "Clinton" ore. John Deming informed the writer that in drilling for Herman Kreuder in sec. 14, T. 2 N., R. 22 E. (Somers Township), Kenosha County, his drill penetrated 50 feet of red and purplish rock, including 18 feet of "iron ore," immediately overlying the shale. Some of the wells, however, are said to have penetrated 40 to 70 feet of dolomite between the red beds and the top of the shale.

[1] Thwaites, F. T., Recent discoveries of "Clinton" iron ore in eastern Wisconsin: U. S. Geol. Survey Bull. 540, pp. 341-342, 1914.

[2] For full record of this well, see Fuller, M. L., and Sanford, Samuel, Record of deep-well drilling for 1905: U. S. Geol. Survey Bull. 298, p. 295, 1906.

[3] Analysis by Lerch Brothers, Virginia, Minn.

At other places two or even three beds of soft red material occur interstratified with dolomite.

In the western part of Racine and Kenosha counties and in eastern Walworth County the removal of the overlying rock brings the red rock up to the base of the drift at intervals over a considerable area. In William Aldrich's quarry, a mile west of Burlington, Racine County, red ocherous beds wholly different in character from those seen at any other place are exposed. This deposit has been included in the Niagara dolomite, but it may perhaps represent some of the beds under discussion. At the time of the writer's visit the quarry hole was full of water, so that the strata could not be seen in place, but rock that had been taken out was exposed in piles near by. This rock is impure, thin-bedded dolomitic limestone, splitting and breaking readily into small pieces. In color it varies from light buff to yellow, reddish yellow, dark red, and purplish red. The red rock, which is softer than the buff and which disintegrates on exposure to red shaly mud, was said to be from the bottom of the excavation. The rock carries crystallized calcite and, especially in the purple layers, abundant fucoidal markings.

This red ocherous rock and the beds of iron ore, whether belonging to the same or to different formations, must have contributed considerable amounts of red material to the drift, especially during the earlier glacial invasions. It is probably this which gives the reddish or pinkish tint to much of the drift of the Illinoian sheet in Walworth and Rock counties and even farther west and south.

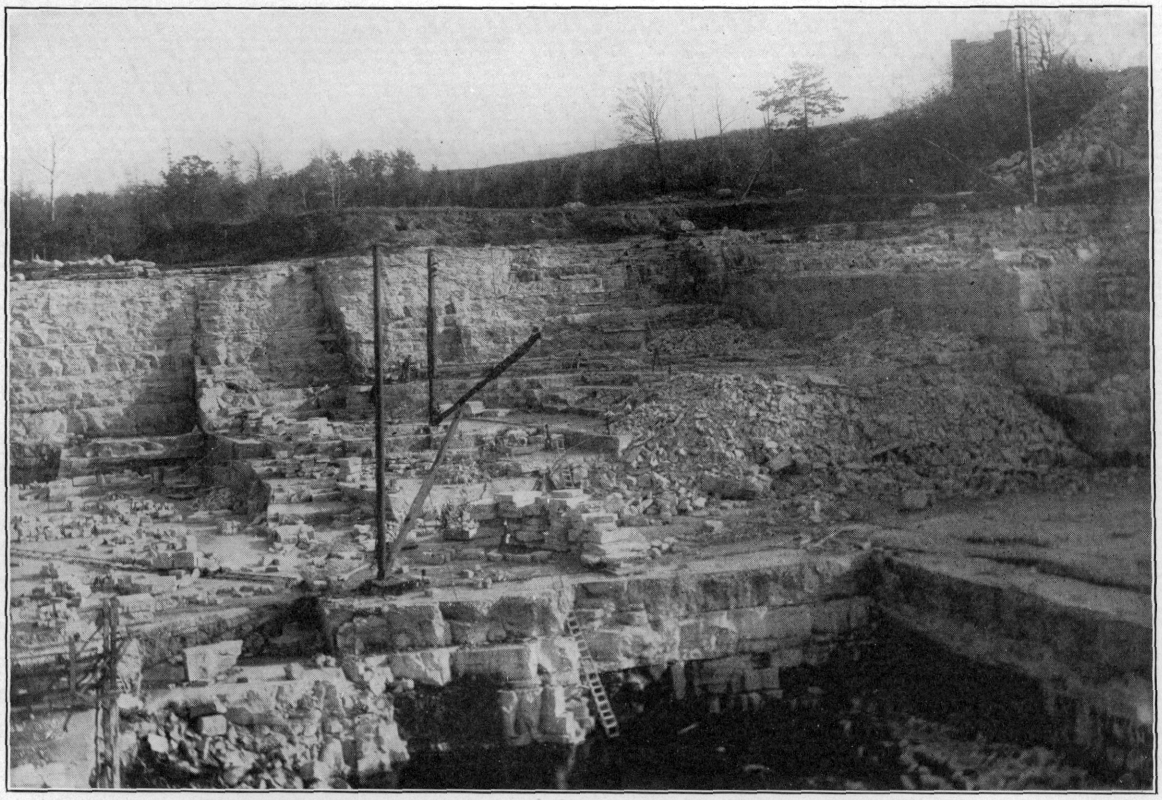
NIAGARA DOLOMITE.

Immediately underlying the drift throughout most of the eastern part of the area is the Niagara dolomite. This formation, which outcrops at intervals throughout a belt 22 to 42 miles in width, extends from north to south along the west side of Lake Michigan. At the west it terminates for the most part in an abrupt margin at the top of the slope in which the underlying shale also ends. Southward from Calumet County through Fond du Lac County and much of Dodge County, this slope forms a bold escarpment rising 100 to 200 feet above the lower tract to the west, being particularly well marked along the east side of Lake Winnebago and the Horicon Marsh. Southward through southeastern Dodge County and thence through Waukesha and Walworth counties this slope is less abrupt, is cut by broad and deep reentrants, and is deeply buried in drift, so that through much of the distance it loses its form as a distinct escarpment and in some places the position of its margin can be only approximately determined by the correlation of data from the relative elevations and the drilling of wells. The moderately undulating surface of the beveled portion of the formation extends eastward beneath the drift, declining gradually to the shore of Lake Michigan, where the dolomite outcrops in several places at the water's edge, thence passing beneath the lake basin.

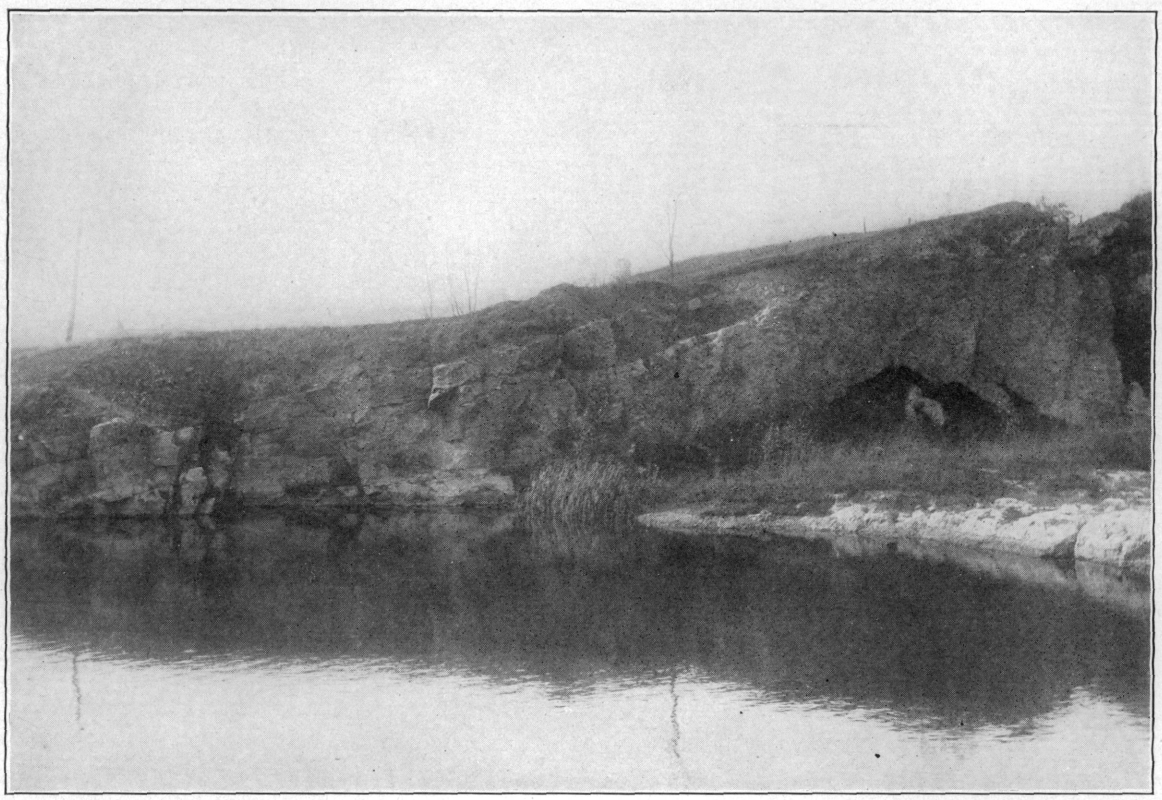
The Niagara dolomite overlies unconformably the eroded surface of the "Clinton" iron ore and the Maquoketa shale and is in turn probably overlain unconformably by later Silurian and Devonian deposits, so that even where these formations remain it is not known that the full original thickness of the formation is present. Where overlain by the drift it is probable that considerable thicknesses of the rock were removed by preglacial erosion, and more or less of it must also have been removed by repeated glaciation, for it forms a very large percentage of the pebbles and bowlders incorporated in the drift throughout this belt. Almost all of the pebbles are of undecomposed dolomite, freshly abraded and often beautifully striated. Except where exposed in the west-facing escarpment the dolomite usually does not show evidence of long exposure to the weather.

CHARACTER.

As a whole the Niagara formation is composed of white to light bluish-gray (on weathered surfaces grayish to buff) crystalline dolomite, or magnesian limestone. It is generally well stratified in regular, little-fractured courses, varying in thickness from a few inches to 30 inches or more. (See Pl. XII, *A*.) Locally it varies in different courses from even, dense, fine-grained rock of conchoidal fracture to granular dolomite of irregular open porous texture, and at some horizons it carries an abundance of chert in well-defined layers. The formation is generally rather fossiliferous and in parts highly so, hundreds of species having been collected from some of the exposures.



A. BUILDING-STONE QUARRY IN NIAGARA DOLOMITE AT WAUWATOSA, WIS.



B. NIAGARA DOLOMITE, REEF ROCK IN OLD QUARRY, WAUWATOSA, WIS.

The well-stratified beds at the left merge into the massive irregular-textured dolomite that forms the body of the rock mound at the right.

Chamberlin [1] made a careful study of the faunal and lithological characters of the several parts of the formation, which he subdivided as follows: At the south, (1) Guelph beds; (2) Racine beds; (3) Waukesha beds; (4) Mayville beds. At the north, (1) Guelph beds; (2) Racine beds; (3) Upper coral beds; (4) Lower coral beds; (5) Byron beds; (6) Mayville beds. The writer has not attempted to trace out these several subdivisions, and they are not indicated on the map (Pl. I).

The Mayville beds of the Wisconsin State Survey reports are thick bedded and of uneven structure, the uneven texture giving rise, on weathering, to rough-pitted ledges so prominently exposed along the escarpment known as "the Ledge." The rock is cut by frequent joints, and at many places along the Ledge large masses have become detached and have slid 5 to 15 feet or so away along the surface of the underlying shale, which is very slippery when wet.

The rock of the Byron beds of the Wisconsin State Survey reports is of finer and of more compact and even texture, giving smoother and whiter ledges. The beds range from thin flagstone to heavy coursing layers.

The highly fossiliferous dolomite of the coral beds is not well exposed within this area.

Overlying the dolomite which the Wisconsin State Survey reports designated the Mayville beds south of Fond du Lac County are the deposits which they designate Waukesha beds. These consist of rather dense, even, fine-grained, crystalline-textured, whitish dolomite, regularly bedded in layers 4 to 30 inches thick. The upper part in some places carries nearly continuous layers of chert in both separate and coalescent nodules.

The next higher subdivision, the Racine beds of the Wisconsin State reports, underlies the larger part of the southern half of the belt of Niagara dolomite. The rock is well exposed in the quarries in the vicinity of Racine and Milwaukee. It is in general a whitish or light bluish-gray crystalline dolomite of four or less distinct varieties, all of which are shown by their relations and fauna to have been either contemporaneous or closely associated in deposition. One variety, a limestone regarded as being especially characteristic of these beds, has a rather open, porous texture. Under a hand magnifier some specimens appear as an aggregation of dolomite crystals with the interstices unfilled, and others appear denser as a whole but pitted with abundant pores and little cavities, either irregular in shape or of the form of fossils which have been removed by solution. This rock is apt to be massive, showing only indistinct lines of bedding, or to occur in heavy beds several feet in thickness.

Another variety, a type largely exposed in the quarries, consists of regularly stratified rock in little-fractured courses, which thicken from a few inches at or near the tops of the exposure to 28 or 30 inches in the bottoms of the deeper quarries. The texture of this rock varies from rather open and porous to fine grained, dense, and even, with conchoidal fracture.

At the Wauwatosa quarries there occur, alternating with the above dense even-textured strata, beds of more or less irregular, coarse, granular, or lumpy texture. The lumpy-textured rock is peculiar. Under the hammer it breaks into angular lumps or granules varying in size from a pea to a hazelnut. Some of it contains a rather loose buff calcareous filling in the interstices between the harder granules. On weathering this filling dissolves out, leaving an irregular open texture. Other layers are of an irregular semilaminate structure, so that while splitting into good building blocks the bedding surfaces are curiously uneven, with small irregular knobs and hollows about an inch in relief. These strata are very hard and do not break readily across the planes of stratification. Five or six of these coarse-grained and irregular-textured layers occur in some of the quarry sections, separated by several layers of even-textured fine-grained rock. Though for the most part these different kinds of rock form distinct strata at some horizons they grade into each other, and in places a thin layer of the coarse, irregular texture runs through the middle of a fine-grained, even-textured stratum with gradations upward and downward. At Story Bros.' quarry at Wauwatosa the coarse-textured layers tend to pinch out laterally. Where this occurs a soft blue clayey shale comes in.

The fourth type of the Racine dolomite of the Wisconsin State Survey reports occurs as mounds or reefs of massive coarse-grained rock, showing little or no sign of bedding, in the midst of regularly bedded dolomite. In places

[1] Geology of Wisconsin, vol. 2, pp. 335-389, 1877.

the cores of these mounds appear to be a breccia of angular fragments of dolomite in a dolomite matrix, which gradually passes laterally into more or less definite layers dipping away from the center of the massive accumulation. (See Pl. XII, *B*.) Near the mound the dip may at first be as high as 30°, but it becomes gradually less with the change in character of the rock, and within a few rods of the place of the initial appearance of the bedding it becomes nearly horizontal. The local dip in the bedding of the stratified rock on the flanks of these mounds appears to be due not to upheaval but to the original slope of deposition, for the bedded rock does not merely lie upon the flanks of the mounds but actually grades into the massive unstratified rock of the cores.

The color of stone of this type is about the same at all the exposures, though it differs somewhat in the larger quarries. Predominantly it is light gray or bluish gray, but in certain of the beds it is almost white and in others it is a delicate buff. In two of the quarries at Wauwatosa, those of the Monarch Stone Co. and of Story Bros., several courses exposed 45 to 60 feet below the surface are mottled pink or purplish, probably from the weathering of scattered crystals of iron pyrites.

With the exception of the beds flanking the dolomite mounds, beds of the fourth type usually dip very slightly, rarely more than 2° to 5°, to the east, though with slight local variations. Though broken in many places by joint planes, along some of which they show slight vertical displacements of a few inches, the beds generally show no evidence of disturbance.

The rock is quite generally fossiliferous, most of the fossils being in the form of casts. At some of the exposures they are very abundant. Several hundred species, including corals, bryozoans, crinoids, brachiopods, gastropods, pelecypods, cephalopods, and trilobites, have been collected by different persons at various times. In the massive rock forming the mounds above described and in the stratified layers on and near their flanks these remains of ancient life forms are especially abundant.

Some dolomite exposed at several points in the eastern part of the Niagara belt was referred to the Guelph beds of the Wisconsin State Survey reports by Chamberlin, not on account of difference in structure and lithologic character, but by reason of the appearance of numerous fossils characteristic of the Guelph formation of the Canadian Survey reports. So far as seen by the writer, the rock exposed resembles the Racine beds of the Wisconsin State Survey reports.

THICKNESS.

The pre-Devonian and preglacial exposure of the Niagara dolomite to erosion make it uncertain, as already stated (p. 90), that its full original thickness remains at any place within the area. The average thickness penetrated by 38 scattered wells, most of which passed entirely through the formation, is 312 feet, the several thicknesses ranging from 120 to 719 feet. With one exception, thicknesses of more than 400 feet occur in Sheboygan County, the maximum, 719 feet, being penetrated by the artesian well at the park in Sheboygan.[1]

ORIGINAL EXTENT.

The Niagara dolomite probably extended originally over most, if not all, the area under consideration. The higher of the Blue Mounds near the west line of Dane County in the towns of Brigham and Blue Mounds (T. 6 N., R. 5 and 6 E.) has an elevation of about 1,730 feet, and is capped, according to Moses Strong,[2] by a very hard flinty rock over 100 feet thick, below which lie the Niagara dolomite and Maquoketa shale. It is evident from the elevation at which these erosion remnants occur (there being no evidence of local upheaval) that the formations to which they belong must originally have had much greater extension. Chamberlin [3] stated his conclusions concerning this as follows:

> When the position and relation of these mounds is considered it becomes quite clear that the Niagara limestone once extended from the eastern portion of the State over the central arch, embracing the Blue Mounds, which stand near its summit, and the Platte, Sinsinawa, and other mounds on its western slope, and joined the great Niagara limestone area that underlies Iowa and Minnesota on the west. But it is manifest that an erosion which swept away 40 miles of strata on the south of the Blue Mounds must, during the same period, have cut away a considerable formation on the north. It is a necessary inference, therefore, that this formation originally covered a very large area in the southern portion of the State. Similar observations upon other formations lead to similar views concerning their former greater extension.

[1] Chamberlin, T. C., Geology of Wisconsin, vol. 2, p. 164, 1877.
[2] Idem, p. 661.
[3] Idem, vol. 1, pp. 259-260, 1883.

Salisbury cites as confirmation of this belief the occurrence of fossils from the Niagara in pebbles of the preglacial gravels which lie on the top of the east bluff at Devils Lake at an elevation about 1,660 feet above sea level. He says: [1]

> It has long been believed that the Niagara limestone of Wisconsin, now confined principally to the eastern margin of the State, once extended much farther west over regions whence it has been removed. The constitution of the gravel affords an interesting confirmation of this belief and seems to indicate that the Niagara may have had even a greater extent than has been supposed, for it can hardly be doubted that when the gravel was formed the limestone either overlay the quartzite or existed at some equally high point in the immediate vicinity. Not only this, but the presence of one fossil, *Orthoceras junceum*, which, so far as known, can be referred only to the Trenton or Galena, suggests that one or both of these formations also once passed over the quartzite ridge, or at least that they were once at equally high points in the immediate vicinity. If these formations once covered the quartzite and were overlain by the Hudson River [Maquoketa] shale, the Niagara limestone, which in Wisconsin immediately succeeds the Hudson River shale, must have originally lain very high above the crest of the quartzite range. If the Trenton lay upon the quartzite directly and if it and the succeeding Galena and Hudson River formations had their usual thickness, the base of the Niagara could hardly have been less than 500 feet above the top of the east bluff at Devils Lake. If the St. Peter sandstone and the Lower Magnesian limestone overlay the quartzite beneath the Trenton, the base of the Niagara must have been still higher.

The Niagara dolomite underlies almost all that part of the area under discussion which was traversed by the Lake Michigan Glacier of the Wisconsin stage of glaciation. A large number of the analyses of the content of the drift of this glacier, made by counting and sorting pebbles, show that of the coarser material of the drift about 75 per cent was derived from this formation. It also seems fair to presume that an equally large percentage of the fine material was derived from the same source.

Similar analyses also show that considerable amounts of Niagara material were incorporated in the Illinoian drift, outside the Wisconsin moraines, some of it being carried westward across the areas of Galena dolomite and Trenton limestone to the border of the Driftless Area, the average of 67 analyses showing about 16 per cent.

In Fond du Lac, Dodge, and Washington counties the Green Bay Glacier overrode the escarpment at the west margin of the formation and traversed the upland to the east, incorporating large amounts of Niagara material in the drift in the eastern part of its area.

As noted above, part of the red ocherous beds discussed in connection with the iron ore deposits (pp. 88 and 89) may really belong to the Niagara dolomite.

WAUBAKEE DOLOMITE (LOWER HELDERBERG OF EARLY WISCONSIN REPORTS).

Throughout most of the eastern part of the area such later Silurian deposits as may originally have overlain the Niagara dolomite were entirely removed prior to the deposition of the drift. At the following localities, however, remnants show the probable former extension of deposits of the Cayuga epoch: (1) Banks of Milwaukee River a mile west of the village of Waubakee, sec. 29, T. 12 N., R. 21 E. (Fredonia Township); (2) quarry of the Northwestern Stone Co., 8 to 9 miles northeast of Port Washington; (3) Dreucker's stone quarry, 3 miles north of Port Washington; (4) banks of Mud Creek, one-half mile south of North Milwaukee (sec. 1, Wauwatosa Township); (5) floor of the Milwaukee Cement Co.'s quarry on Milwaukee River at Berthelet, one-half mile north of the Milwaukee city limits; (6) (beds probably to be correlated with the above) artesian well at Lake Park, Milwaukee, and test borings for the waterworks intake tunnel at North Point; (7) sec. 10, T. 8 N., R. 21 E. (Granville Township), small exposure possibly to be correlated with these deposits.

As the formation is not well known and its age has been questioned it may be permissible to present here somewhat in detail observations on it made by the writer and others.

The name Waubakee formation was used by the writer [2] in 1906 for deposits correlated with those exposed near Waubakee, Ozaukee County, all of which had been provisionally correlated by Chamberlin,[3] on the evidence then available, with the "Lower Helderberg" of New York. In concluding his discussion of the probable age of the deposits near Waubakee, Chamberlin wrote: [4]

> It is evident from these facts that the stratigraphical relations of the deposit contribute nothing but negative

[1] Salisbury, R. D., Preglacial gravels on the quartzite range near Baraboo, Wis.: Jour. Geology, vol. 3, pp. 666-667, 1895.

[2] U. S. Geol. Survey Geol. Atlas, Milwaukee folio (No. 140), p. 2, 1906.

[3] Geology of Wisconsin, vol. 2, pp. 390-394, 1877.

[4] Idem, p. 394.

indications, and the question of its age and equivalency must rest upon its lithological character and organic contents. While it is evident that neither of these is decisive, yet it is apparent that the weight of their testimony is in favor of referring the formation to the base of the Lower Helderberg group. The same may be said of the formation near Milwaukee.

James Hall[1] regarded the thin-bedded limestone exposed on Mud Creek a few miles northwest of Milwaukee as belonging to the "Onondaga salt group" (Salina formation).

The character and relations of the deposits at these several points can best be presented by a discussion of local details. The following is the section exposed at an old quarry in the north bank of Milwaukee River a mile west of Waubakee, as described by Chamberlin:[2]

Section of Waubakee limestone, sec. 29, T. 12 N., R. 21 E. (Fredonia Township), Ozaukee County, Wis.

	Ft.	In.
Light-gray thin-bedded shaly dolomite, resembling that occurring on Mud Creek but less porous. The surfaces of some of the layers are covered with large numbers of a *Leperditia*, undistinguishable from *Leperditia alta*	2	0
A layer of hard dolomite containing cavities, some 5 or 6 inches in diameter, which are usually filled with large crystals of calcite. *Leperditia* occurs occasionally in this layer		10
Alternating thin and thicker beds similar to No. 1 in lithological character; some layers are marked with a dark, rusty coating	2	2
Similar to No. 2	1	2½
Moderately thick beds, somewhat shaly, intermediate in character between the thinner and thicker beds above	1	0
	7	2½

The remains of *Leperditia* found at this locality are very abundant, literally covering the surface of some layers and to a greater or less extent disseminated through the mass of some of the beds, but unfortunately the state of preservation is poor. A careful examination and comparison of a large number of specimens leaves no doubt that the fossil is *Leperditia alta*, or a very closely related species.

In the bed of the river a little above this locality very thin beds of a softer dark dolomite, colored by carbonaceous matter, are found. Some of the layers are marked by numerous black or dark brown carbonaceous laminæ, which gives to the rock an appearance quite peculiar. This carbonaceous matter is evidently derived from the remains of plants, many indications of which are present, among them forms resembling *Sphenothallus*. In addition to these, two species of *Orthis* are found, one resembling *Orthis oblata* and the other closely similar to *Orthis subcarinata* but smaller. *Pterinea aviculoidea*, or a very closely allied if not absolutely identical species, an imperfect *Orthoceras*, and a doubtful *Inocaulis* are also present.

A little farther west, on the south side of the stream, a small quarry about 7 feet deep has been opened in the flat on land which when visited by the writer belonged to Julius Klessig. The rock as exposed is a very brittle, hard buff to grayish, thinly laminated, impure dolomite, quarrying out in layers varying in thickness from a fraction of an inch to 4 inches. On the north side of the excavation the beds dip 15° N. 30° E., and on the east side they dip 14° N. 70° E. Material thrown out from the lower part of the hole, now filled, is more bluish and somewhat fossiliferous. E. E. Teller and C. E. Monroe, of Milwaukee, collected from this material thrown out specimens of three species of fossil shrimps described and named by R. P. Whitfield[3] (*Entomocaris telleri*, *Ceratiocaris monroei*, and *C. poduriformis*). The writer also collected from this material fragments of *Ceratiocaris monroei*, numerous caudal spines and mandibles of the same genus but specifically undeterminable, and much flattened specimens of a brachiopod comparable to if not identical with *Rhynchonella ? hydraulica* Whitfield.

Charles Schuchert, to whom a part of the specimens were referred, states as the result of their examination that the Waubakee dolomite is in the Silurian beneath the Manlius and is equivalent to a part or all of the New York Salina. E. M. Kindle, who also examined part of the specimens, refers the Waubakee to the Cayuga epoch but considers the evidence insufficient to justify correlation with any single formation of the Cayuga group of New York.

The extent of the Waubakee dolomite is not known, as no other exposures occur in this vicinity and the covering of drift is generally thick. It is, however, probably only a very small erosion remnant. The exposures on Milwaukee River lie about 800 feet above sea level, and wells within a mile to the southwest and southeast show the rock surface there to be as low as 720 to 740 feet above sea level. To the north and northwest the rock surface rises beneath the drift, but an exposure at 860 feet above sea level at Kohler, 1½ miles northwest of the quarries on the river, is of Niagara dolo-

[1] Hall, James, and Whitney, J. D., Report on the geological survey of the State of Wisconsin, vol. 1, p. 70, 1862.

[2] Op. cit., p. 392.

[3] Whitfield, R. P., Notice and description of new species and a new genus of Phyllocaridæ: Am. Mus. Nat. Hist. Bull., vol. 8, pp. 299-304, 1896.

mite. Other exposures, one on the river 2¼ miles southeast about 800 feet above sea level, and one at Newburg, 3½ miles southwest, 860 feet above, are also of Niagara dolomite.

At Dreucker's quarry, about 7 miles southeast of the Waubakee exposure, and at the quarry of the Northwestern Stone Co. (or Lake Shore Stone Co.), on the lake shore between 10 and 11 miles nearly due east of the Waubakee exposure, thin-bedded limestone is exposed between the Milwaukee formation above and the Niagara dolomite below. H. F. Cleland[1] correlates these exposures with the Waubakee dolomite. The deposits consist of 2 to 2½ feet of a wavy thin-bedded nodular limestone with clayey partings, which unconformably overlies the Niagara dolomite and unconformably underlies the Milwaukee formation. The relations as seen at the quarry on the lake shore by the present writer in 1908 are shown in figure 4 (p. 99). The credit for the correlation, however, both here and at Dreucker's quarry, belongs to Cleland.

Deposits exposed 26 miles south of Waubakee and about one-half mile south of North Milwaukee at the quarry of Emil Petzold and about one-fourth mile to the west are believed to belong to the same horizon as the Waubakee, though the identification is based chiefly on stratigraphic position and chemical composition, fossils being very rare. The rock at Petzold's quarry, of which 10 or 12 feet is exposed, is gray to brownish gray, finely laminated, dolomitic limestone, splitting readily into slabs one-half inch to 4 inches in thickness. The lower strata are more unevenly bedded, with streaks of blue clay. In general the strata are very nearly horizontal, but at the western exposure dip 5° E.

Underlying the cement rock at the quarry of the Milwaukee Cement Co., in the valley of Milwaukee River, one-half mile north of the Milwaukee city limits, is a porous brownish limestone believed to be the continuation of the rock seen at Petzold's quarry, 2½ miles west. Only the undulating upper surface and 1 to 2 feet in section have been exposed, and no fossils have been found. It is also reported that a brownish limestone underlies the cement rock at the quarry of the Consolidated Cement Co. on the shore of Whitefish Bay. It is not, however, well exposed to examination.

In boring for the artesian well at Lake Park 30 feet of brownish limestone was found 282 feet below the surface, or about 204 feet below the level of the lake. This brownish limestone is here immediately above the Niagara dolomite and immediately below the beds of the Milwaukee formation. So likewise, the test borings for the intake tunnel at North Point show 10 feet of brownish stone between the Milwaukee formation and the Niagara dolomite. There seems to be little doubt as to the dentity of the brownish limestone shown by these several borings and that which forms the floors at the cement quarries.

The only fossils reported from this formation near Milwaukee are from the exposures on Mud Creek. These were fair specimens of *Meristella nucleolata*, an *Orthis* resembling a young *O. oblata*, and an imperfect specimen of *Meristella* or *Pentamerus*, all found by Chamberlin.

Analyses of the rock from several of the exposures show close similarity in composition and strengthen the belief as to their equivalence in age.

DEVONIAN ROCKS.

MILWAUKEE FORMATION (HAMILTON OF EARLY WISCONSIN REPORTS).

Closely bordering the shore of Lake Michigan are certain deposits, emerging from beneath the lake, which have been referred to the Hamilton. The discovery of these deposits was first reported by I. A. Lapham[2] in 1860 and they were studied and described by Chamberlin[3] in 1877. In the Milwaukee special folio[4] they were designated the Milwaukee formation from their exposure in the quarries of the Milwaukee Cement Co. near Milwaukee.

As nearly as can be determined the formation has the following generalized section:

Generalized section of the Milwaukee formation near Milwaukee, Wis.

	Feet.
Black shale	0–15
Soft bluish "soapy clay" or shale	0–80
Bluish hydraulic limestone, cement rock	0–12
Bluish hydraulic limestone and softer bluish "soapy clay"	0–31

[1] Cleland, H. F., The fossils and stratigraphy of the middle Devonic of Wisconsin: Wisconsin Geol. and Nat. Hist. Survey Bull. 21, sci. ser., No. 6, pp. 8–10 and pl. B, 1911.

[2] Lapham, I. A., Discovery of Devonian rocks and fossils in Wisconsin: Am. Jour. Sci., 2d ser., vol. 29, p. 145, 1860. Also St. Louis Acad. Sci. Trans., vol. 1, p. 684, 1860.

[3] Geology of Wisconsin, vol. 2, pp. 395–405, 1877.

[4] U. S. Geol. Survey Geol. Atlas, Milwaukee special folio (No. 140), p. 3, 1906.

So far as observed these beds, with the exception of the upper black shale, are highly fossiliferous, showing a great variety of remains of invertebrate life as well as plates and teeth of armor-plated fishes. The fossils are in part silicified, in part pyritized, and in part casts of the organic remains. Beneath these deposits in and near the northeastern part of the city of Milwaukee is the brownish limestone correlated with the Waubakee dolomite.

The stratigraphic relations of the formation are shown in figure 4 (p. 99).

The best exposure of beds belonging to this formation is afforded by the quarries of the Milwaukee Cement Co. in the valley of Milwaukee River, one-half mile north of the city limits. There is here a 25-foot section resting upon the brownish limestone which has already been described (p. 95). The strata are very slightly undulating, with a gentle dip toward the southeast. The rock is here a bluish hydraulic limestone, rich in magnesia, alumina, iron, and silica, and showing abundant fossils. The lower 15 feet is rather soft and in places very soft and shaly. Above is a very hard stratum 6 feet thick, and at the top 4 feet of shaly rock readily disintegrating on exposure, but with thin, hard layers bearing silicified fossils. The top of this section is 30 feet above Lake Michigan.

The rock forms the bed of the river for some distance above the cement quarries, and also southward to the Washington Street Bridge.

Three miles north of the quarries of the Milwaukee Cement Co., at the foot of the bluff on the shore of Whitefish Bay, there is an exposure of the Milwaukee formation a few feet above the water's edge. Near this point the Consolidated Cement Co. opened a shaft to supply their mill on the bluff above. This shaft extends 22 feet below the level of the beach, where it connects with a main gallery which at the time of the writer's visit extended 210 feet north and south. From this gallery drifts were being extended westward in the working beds. The upper 5 to 6 feet was left as roofing and was not well exposed to examination, but material thrown out in excavating the shaft through these showed them to be of moderately hard fine-grained bluish-gray hydraulic limestone, characterized by an abundance of pyritized fossils, crystals of pyrite and of calcite, and traces of bitumen. The working face, which had a maximum height of about 14 feet, showed dense bluish-gray massive to heavy-bedded hydraulic limestone having the same general appearance as that at quarries on the river but with the bedding planes less distinctly marked. So far as could be seen this part appears to be less fossiliferous than the beds composing the roof and than those exposed along the river. The bedding is slightly undulatory, so that, though the general dip of the formation is toward the east, in the northern part of the exposure it is slightly toward the west.

Between 1885 and 1900, in extending the water system of the city of Milwaukee, a shaft 130 feet deep was sunk on the beach at the North Point pumping station, and from the bottom of this an intake tunnel was projected under the lake 3,200 feet. Preliminary test borings showed below the lacustrine deposits and the drift the beds of the Milwaukee formation in fuller series than at the quarries on the river. At a depth of 42 feet below the water level, as shown by the records of the city engineer's office, the shore shaft penetrated 15 feet of black shale. Below this, in succession, were 40 feet of "blue, soapy clay," 10 feet of cement rock, and 31 feet of "blue, soapy clay." At the depth of 138 feet "brown stone and lime rock" was reached. The latter rock was penetrated for but a small depth, so the identification is not positive, but, as already indicated, it seems probable that the "brown stone" is the same as that in the bottom of the quarries on Milwaukee River and at Mr. Petzold's quarry on Mud Creek, and that the "lime rock" is the Niagara dolomite.

The 8-foot intake tunnel was projected through the lower bed of "soapy clay," so that the material excavated from the tunnel and from the shaft, which was dumped upon the beach near by, gave opportunity for examination and identification of the beds of the group. This has since been spread out upon the beach and is now largely covered by the soil, grass, and trees of a small park, so there is little chance for further examination. The "soapy clay" or soapstone is a lumpy, nodular shale of greenish-gray color, soft when wet but hardening to a shaly rock when dry, and readily disintegrating to clay on exposure to the weather. It strongly resembles the material seen on the shore of Whitefish Bay and some of the lowest and highest beds at the cement quarry on the river.

Portions of the "soapstone" carry fossils, in an excellent state of preservation, and for the most part of the same species as those found at the two exposures. Other portions of the "soapstone" are almost wholly devoid of fossils. In this they resemble some of the softer layers near the bottom of the cement quarry.[1]

The material dumped on the beach also showed harder portions similar in color to the harder cement rock but traversed by very hard white seams of a siliceous character. These seams are full of fossils, most of which are found at the Milwaukee Cement Co.'s quarry. There is thus no question as to the identity of the beds here found. This series of "soapstone" or "soapy clay" and cement rock is shown both by the shore shaft and by a boring 2,060 feet from the shore line, with the difference that in the latter the underlying brown stone has declined to a depth of 180 feet below the lake surface, and the lower bed of the soapy clay has thickened to 60 feet. The cement rock continues at the same thickness, having declined only 10 or 12 feet. The upper bed of "soapy clay" has thinned to 15 feet, and the black shale is no longer seen, evidently having been removed by erosion. Five other borings at varying distances up to 3,200 feet from the shore shaft show the presence of the soapstone clay and cement rock, but none show the black shale. One boring, 1,500 feet from the shore, shows but 19 feet 4 inches of the lower soapstone clay yet remaining over the limestone, the whole superjacent thickness of the group having been removed by erosion and replaced by drift.

The log of the artesian well at Lake Park, near the crest of the bluff, a mile north of the North Point pumping station, shows the presence of the Milwaukee formation, with the exception of the upper black shale, which has here also been removed by erosion. The beds immediately underlie the drift and are reached about 80 feet below the lake level.

The succession here, beginning at the top, is as follows:

Partial log of the well at Lake Park, Milwaukee, Wis.[2]

	Feet.
Drift: Red clay, lacustrine or glacial; sand and gravel and till	160
Milwaukee formation:	
Soft shaly rock	80
Cement rock	12
Soft shaly rock	30
Waubakee dolomite, brown	30

The city engineer's profile of the deposits penetrated by a series of test borings along the line of Glen Avenue from the North Point pumping station to Whitefish Bay also shows the presence of beds belonging to this formation beneath the drift. Three of the borings penetrated 10 feet or so of black shale overlying "soapstone clay" (soft shaly material). Elsewhere the black shale is absent, probably having been removed by erosion. Considerable amounts of this black shale are present as fragments in the drift at some points. All the borings but one show the presence of the upper bed of soft shaly material. Comparing the section afforded by these drill holes with the log of the Lake Park well and with that of the shore shaft, it appears very probable that the "lime rock" reached but not penetrated by these borings is in reality the same as the "cement rock" of the Lake Park well, the borings for the intake tunnel beneath the lake, and the heavy stratum seen at the cement quarries on the river.

A cut on the Chicago, Milwaukee & St. Paul Railway just south of Brown Deer station, 5 miles north of North Milwaukee, exposed Devonian rock of the same formation. The rock here slightly exposed is a thin-bedded buff, very fossiliferous limestone, abundant fragments of which are contained in the drift above it. The rock is much more weathered and decomposed than at the other exposures, but the abundant fish remains, brachiopods, and pelecypods indicate that it is the same. Rock also occurs in the bed of Milwaukee River at several points but is nowhere conveniently exposed to examination.

Chamberlin[3] described an occurrence of Devonian rock at Granville Center which is no

[1] Monroe, C. E., and Teller, E. E., The fauna of the Devonian formation at Milwaukee, Wis.: Jour. Geology, vol. 7, No. 3, p. 272, 1899.

[2] F. M. Gray, driller, Milwaukee, Wis.

[3] Geology of Wisconsin, vol. 2, pp. 391 and 399, 1877.

longer accessible. Concerning this he makes the following statement:

In the northwest quarter of section 10 and in the northeast quarter of section 9 of the town of Granville we find the most northwesterly known exposure of the * * * Hamilton [Milwaukee] formation in the brow of a hill facing the northwest. Only 30 paces down the gentle slope from the Hamilton beds, a pit has been opened which discloses the Niagara limestone. The vertical distance between the top of the Niagara exposed and the bottom of the quarry of Hamilton rock is about 6 feet. The intermediate slope is largely occupied with old pits now filled, but in the material thrown from them only Niagara and Hamilton rock were seen. In the gutter of the adjacent road both the Hamilton and Niagara are shown, with a vertical distance of less than 5 feet between them, and in the abundant chip stone of the gutter there is none of the shaly limestone [Waubakee dolomite] * * *. But it is a rock peculiarly liable to break up into chip stone and is abundant in the drift near known outcrops and in the line of drift from them. In view of all these facts the shaly limestone [Waubakee dolomite] must be regarded as absent at this point.

The [Milwaukee] rock here is rather soft, granular, buff, impure dolomite, much stained with iron, doubtless due to the decomposition and oxidation of pyrites originally disseminated through it. *Orthis impressa, Strophodonta demissa, Spirifera pinnata, Atrypa occidentalis*, and *A. reticularis* show the character of the fauna.

The Milwaukee formation is exposed at several points on the shore of Lake Michigan in the northeastern part of Ozaukee County in sec. 19, T. 12 N., R. 23 E., and sec. 36, T. 12 N., R. 22 E. (Belgium Township), and in secs. 1 and 9, T. 11 N., R. 22 E. (Port Washington Township). At the first exposure, 3 miles east of the village of Belgium, the Northwestern Stone Co. (or Lake Shore Stone Co.) has opened a quarry which, at the time of the writer's visit in 1908, exposed the following section:

Section of Northwestern Stone Co. quarry east of Belgium, Wis.

	Feet.
Milwaukee formation:	
Dark brownish-gray uneven-textured limestone, dolomitic, containing many small cavities. Partly almost as hard as chert. Bedded in 4 to 8 inch layers	4–8
Unconformity.	
Waubakee dolomite:	
Shaly bluish-gray limestone, dolomitic, thinly laminated and interbedded with lenses of harder limestone of small and varying thickness	3
Unconformity.	
Niagara dolomite:	
Porous grayish-white dolomitic crystalline-textured limestone in one heavy bed	3
Same, but denser and bedded	18
Same, open, porous	2½
Same, but dense	12

Several years earlier, when there was but a small opening at this place, the writer collected numerous fossils from the upper beds. From an examination of these and other fossils E. M. Kindle reported that the fossils from sec. 19, T. 12 N., R. 22 E. (Belgium Township), and those from Brown Deer station near Milwaukee, though indicating a slightly different facies, represented essentially the same fauna as that of the cement rock at Milwaukee. The fauna of the cement beds is composed largely of species common in the Hamilton of the New York section and is its western equivalent.

C. E. Monroe,[1] of Milwaukee, in discussing the fauna of the upper beds then exposed at this place, writes in part as follows:

About 60 species of fossils have been obtained from the upper layers, all of which, with the exception of a single fragmentary dental plate of *Rhynchodus*, are in the form of casts and impressions, a fact which renders their determination a matter of some difficulty. The fauna comprises about 24 species of brachiopods, 12 or 13 of gastropods, 9 corals, and half a dozen pelecypods. *Orthoceras, Rhynchodus*, and *Proetus* are each represented by a single species; there are scattered crinoid joints and a few other species whose generic relations have not yet been satisfactorily determined.

The fossil fauna collected from the several exposures of the Milwaukee formation in eastern Wisconsin is described in detail by H. F. Cleland,[2] who, in discussing the deposits at the Lake Shore Co.'s (or Northwestern Stone Co.'s) quarry east of Belgium, refers the thin-bedded rock lying unconformably between the fossiliferous Milwaukee formation above and the Niagara dolomite beneath to the Waubakee dolomite.

The relations as seen in the west side of the quarry in 1908 are shown in figure 4, *A*. Here the unconformity between the shaly beds and the Niagara dolomite is quite distinct. In *B*, on the south side of the quarry, shaly material fills cracks extending from the base of the shaly beds down into the Niagara dolomite. In *C* the upper beds are missing, the Niagara dolomite was step-faulted with a total vertical drop of 3½ feet on the east side of the shear zones, and the shaly beds extend down over the fault but are disturbed at the shear zones, showing

[1] Monroe, C. E., A notice of a new area of Devonian rocks in Wisconsin: Jour. Geology, vol. 8, pp. 313-314, 1900.

[2] The fossils and stratigraphy of the Middle Devonic of Wisconsin: Wisconsin Geol. and Nat. Hist. Survey Bull. 21, Sci. ser. No. 6, 1911.

that the faulting took place subsequent to their deposition.

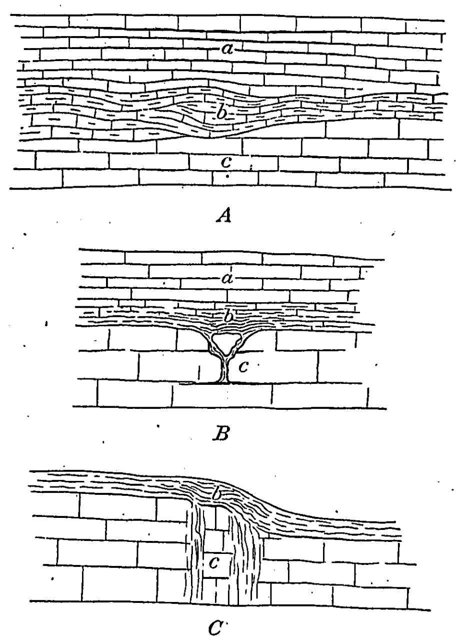


FIGURE 4.—Sections showing unconformable relations of Milwaukee formation (*a*), the Waubakee dolomite (*b*), and Niagara dolomite (*c*) at Northwestern Stone Co.'s quarry, near the lake shore east of Belgium, Ozaukee County., Wis., as seen in 1908. *A*, West face of quarry; *B*, south face; *C*, north face.

Cleland also identified the upper 6 feet of the rock exposed at Dreucker's quarry, 3 miles north of Port Washington, as belonging to the Milwaukee formation by means of fossils which he collected therefrom.

These occurrences of Devonian limestone and shale along the west shore of Lake Michigan are interesting as showing that the basin of the lake is excavated, probably very largely, in the belt of Devonian shales as the Green Bay-Winnebago trough is excavated in the Maquoketa shale belt. It is not improbable that the depth and dimensions of the lake basin are in large measure due to the comparative ease with which erosion was accomplished in these Devonian deposits.

Considerable amounts of material from the Devonian are to be seen in the drift of eastern Wisconsin, and fragments carrying such fossils found in the Illinoian drift west of Rock River show the easterly derivation of the drift in that area. Chamberlin noted the occurrence of black shale in the drift before it was known that the black shales occurred within this area and beneath the margin of the lake. It is possible that the incorporation of sticky aluminous clay from the Devonian shales in the drift of the Lake Michigan Glacier played much the same part in the development of drumlins in the eastern part of the area as adhesive clay from the Maquoketa shale is supposed to have played in the formation of the drumlins of the Green Bay Glacier.

TERTIARY (?) DEPOSITS.

The vast interval between the withdrawal of the waters of the Devonian seas from the borders of southeastern Wisconsin and the incursion of the glaciers of the Pleistocene is recorded in the work of stream erosion as represented in physiographic development and preglacial topography. It is, however, almost wholly unrepresented by geologic deposits. Only one deposit remains, very insignificant in amount but highly significant in character and relations. This is the preglacial gravel on the quartzite range near Baraboo, which has been described by R. D. Salisbury.[1]

Among the quartzite blocks near the top of the "mountain path" from Kirks to the crest of the east bluff of Devils Lake lie fragments of chert and rounded pebbles which have evidently fallen from the crest above. In places at the crest of the bluff where the quartzite is stripped of its soil occur scattered pebbles entirely different from those in the glacial drift whose margin lies a short distance eastward. Careful search among these pebbles has failed to reveal a single piece of rock which was unquestionably derived from the glacial drift. The pebbles, most of which are less than an inch in diameter, and the fragments and nodules are principally of chert ranging in color from white through red, yellowish, ocher, brown, and black. With these are some of vein quartz. The original surfaces of the nodules, where retained, are rather rough or dull, not polished. Many of the pebbles are smoothly rounded, but nearly as many are only subrounded, or angular with the edges slightly worn. Fragments, both rounded and angular, are highly polished; some of them contain parts of silicified fossils.

In 1874 Chamberlin[2] wrote of these deposits in part as follows:

On the high bluff just east of the lake, in excavating for a cistern, Trenton fossils in a silicified condition were

[1] Salisbury, R. D., Preglacial gravels on the quartzite range near Baraboo, Wis.: Jour. Geology, vol. 3, pp. 655–667, 1895.

[2] On the fluctuation of level of the quartzites of Sauk and Columbia counties: Wisconsin Acad. Sci. Trans., vol. 2, pp. 133–138, 1874.

thrown out. This portion of the bluff does not seem to have been visited by the glacial agencies, although northern drift occurs a short distance east. This will not seem strange when it is known that the drift, even on the lower lands, extends but a shorter distance west of this. There was no foreign drift discernible in the material excavated or in the vicinity, and the quartzite bottom did not indicate glacial erosion. These facts, whatever may be thought of their force or conclusiveness, are at least interesting.

Somewhat back from the crest of bluff near an old log cabin is an old well, or cistern, possibly the one referred to by Chamberlin. This, according to Salisbury, was dug to a depth of 16 feet in gravel, beneath which was the firm quartzite, which, according to those who dug the well, was much worn and polished and marked by potholes. Potholes are also observed in the surface of the quartzite in the vicinity, and some of these contain gravel of the same sort. When examined by the writer in 1903 and 1907 the old well was nearly filled by caving and the falling in of débris. Digging into the sides of the hole to a depth of 4 feet below the surface disclosed very sticky noncalcareous bluish clay, mottled yellow, scattered through which were pebbles and chert fragments similar to those which had been left by washing away of the clay in the material thrown out from the old well and that on the crest of the bluff. No bed of sand or loose gravel was reached in the small amount of digging which was done at the time of the writer's visits, nor did the pebbles seem to increase in amount with increasing depth. In a new hole, which was opened to a depth of 3 feet, numerous fragments of quartzite were found just below the sod, and below this was sticky blue clay, with a very few cherts and quartzites. From Salisbury's description it is inferred that a considerable bed of the gravel was found in digging this well. He makes no mention of the sticky blue clay through which pebbles are scattered near the surface, yet the washing of this clay yields fragments and worn pebbles similar to those found on the crest of the bluff. He states, on the contrary, that "the gravel is unaccompanied by the clay and sand beds which are present in Minnesota and on which the Cretaceous correlation was suggested."[1] Some of the chert occurs in sharply angular pieces several inches in diameter, and much of it resembles that disseminated in masses through the Lower Magnesian limestone. It is also like the chert from the Niagara dolomite, so abundant in large masses and in smaller angular fragments on the crest and slopes of West Blue Mound. That some of the material originally came from the Niagara and some from the Trenton and Galena limestones is shown by the fossils which Salisbury[2] cites as having been determined from the material by E. C. Quereau. He says:

> Among the silicified fossils which enter into the gravel as constituent pebbles, there were found representatives of the following groups: Orthoceratites, gastropods, brachiopods, crinoids, bryozoa, and corals. The following forms are recognizable: *Astrocerium venustum* Hall, *Favosites niagarensis* Hall, *Fenestella* cf. *termiceps* Hall, *Callopora* cf. *elegantula* Hall, *Retepora* sp. indet., *Zaphrentis* cf. *turbinata* Hall, crinoid trochites, gen. indet., *Orthoceras junceum* Hall. Of all the determinable species, five belong to the Niagara of Wisconsin and one to the Trenton or Galena.

Among pebbles collected by the writer a few contained traces of fossils, on which Ulrich reports as follows:

> The largest piece, evidently broken from a bowlder of rusty-gray chert, contains part of the corallum of a species of *Favosites* allied to *F. asper*. Both the fossil and the matrix suggest lower to middle Niagaran.
>
> Only two of the five small, evidently desert-polished gray-black chert pebbles are recognizably fossiliferous. One of these retains a small portion of a cyathophylloid coral, evidently having short septa and well-developed tabulæ. These features suggest *Amplexus*, *Campophyllum*, and *Diphyphyllum*. On account of the large size of the original—it must have been over an inch in diameter—and very small width of its septa, the resemblance leans to the first rather than the second and third of these genera.
>
> The second pebble contains a small piece of sponge apparently closely allied to if not identical with *Climacospongia radialis*. So far as known, this genus is confined to a late middle Silurian limestone (Brownsport formation) in west Tennessee.
>
> If we may rely on the last, the polished pebbles also are of Silurian age. The coral, if really *Amplexus*, does not oppose this determination.

On the south quartzite range west of Devils Lake there is a great deal of yellowish chert resembling that just described as occurring with brown loamy clay 2 to 6 feet in depth, and in places with reddish residual clay. Not much of this chert is found more than 1,300 feet above sea level, and the deposit is believed to be the residuum, in large part at least, from the now dissolved Lower Magnesian limestone which probably lapped upon the quartzite ridge at about the same elevation. Some of the chert is in masses a foot or more in size, and

[1] Salisbury, R. D., op. cit., p. 664.

[2] Idem, p. 656.

resembles that occurring in the Lower Magnesian limestone. Most of it is in smaller fragments. It is also like that on West Blue Mound, noted above.

From these relations, it appears that when decomposition and erosion had removed the superincumbent sedimentary formations and had so far lowered the land surface that the crest of the quartzite range was beginning to emerge in the plain, there was a considerable amount of chert on the surface with the other residuals. A part of this was worked over by a stream, possibly by the ancestral Wisconsin River, and was smoothly rounded and polished, as it would be if it were used as in abrading the potholes that pit the quartzite on the bluff east of the Devils Lake Gorge. As these gravels are clearly not glacial, they must be preglacial, as pointed out by Salisbury, and they must have been deposited as gravels when a stream flowed on a level with the top of the quartzite bluff. The level is about 1,560 feet above sea level, 700 feet above Baraboo River on the north, 800 feet above Wisconsin River on the south and fully 1,000 feet above the bottoms of the preglacial channels north and south of the range and through the Devils Lake Gorge. Not only were the valleys cut to this depth since the deposition of the gravels, but hundreds of feet of sedimentary rock has been removed from extensive surrounding areas, so that it is clear that the time since they were deposited has been very long. Their age can hardly be regarded as later than Tertiary. The writer made an examination of the top of West Blue Mound, with a view to ascertaining whether or not such gravels were preserved on that high point. He found a great deal of chert similar in kind to that on the Baraboo Bluffs, much of it in large masses on the slopes, and a large amount of it in smaller fragments on the crest and slopes of the eminence. No excavation was made, but careful examination of the material thrown out from post holes of the observation tower and of that scattered about on the surface and exposed in gullies failed to reveal any water-worn material.

The writer is inclined to think the water-worn pebbles on the bluff east of Devils Lake are local river gravels, but such gravels may have extended on down the valley to the Mississippi embayment. Certain occurrences of conglomerate in the drift indicate that such gravels may originally have had considerable extent. One of these occurrences observed by the writer is in the northwestern part of Whiteside County, Ill., 7 or 8 miles northwest of Morrison. At this place, in a ravine in the south part of sec. 11, Ustick Township, among other erratics were numerous pieces of dark-red ferruginous conglomerate carrying yellow chert pebbles. There is, of course, a possibility that this may be a conglomerate of early drift gravels, as are some ferruginous conglomerates in the Rock River valley near Rockford. When seen by the writer, however, it was thought not to be of glacial origin inasmuch as no crystalline pebbles were noted therein, and inasmuch as it had been solidified to a hard conglomerate prior to its incorporation in the drift.

Salisbury [1] discusses the occurrence on high points in the Mississippi Valley as far north as Pike and Hancock counties, Ill., of similar gravel deposits some of which were noted long ago by Worthen and his associates of the Illinois Geological Survey.[2] He also refers to deposits of quartz gravel in the Driftless Area as far north as Dunn County, Wis., one of which, high on the divide between the Kickapoo and Mississippi rivers in Crawford County, was described by Moses Strong[3] as follows:

> A very singular deposit was found at the village o Seneca, in Crawford County, in the lower part of the Buff limestone. It forms a small eminence a short distance north of the village. The deposit consists of a conglomerate, formed of quartz pebbles of small size, and sand in large rounded grains, firmly united with iron as a cementing material. The pebbles are seldom more than half an inch in the longest dimension, consisting always of white or transparent quartz, and always smoothly rounded, evidently having been rolled by the action of water. The extent of the deposit is small, covering only about an acre, and not exceeding 5 or 6 feet in depth.

It is stated by Chamberlin and Salisbury [4] that this deposit not only lies on the surface but extends down a fissure to a depth of 65 feet, to which extent it was penetrated by a mining shaft.

[1] Op. cit. Also, On the northward and eastward extension of the pre-Pleistocene gravels of the Mississippi basin (abstract): Geol. Soc. America Bull., vol. 3, pp. 183-186, 1892; also Am. Geologist, vol. 8, p. 238, 1891.

[2] Worthen, A. H., Geol. Survey Illinois, vol. 1, p. 331, 1866, and vol. 4, p. 37, 1870.

[3] Strong, Moses, Geology of the Mississippi region north of the Wisconsin River: Geology of Wisconsin, vol. 4, p. 88, 1875-1879.

[4] Chamberlin, T. C., and Salisbury, R. D., The Driftless Area of the upper Mississippi Valley: U. S. Geol. Survey Sixth Ann. Rept., p. 275, 1885.

W J McGee[1] described under the name of Rockville conglomerate similar occurrences crowning one of the higher points in Delaware County, Iowa. He states that "while the pebbles are predominantly quartz, rounded or subangular fragments of chert are not rare, and now and then rounded pebbles of limestone and granitoid rocks occur." He says further that isolated remnants of quartz-pebble conglomerate in a limonite matrix occur occasionally in the extreme northern part of Iowa, and that similar conglomerates form a considerable element in the drift of northeastern Howard and western Winnesheik counties, Iowa. He also cites the observation of similar conglomerate in Illinois by Worthen and his associates at various places in position and in the drift, and the noting of lithologically similar conglomerates of Cretaceous age by N. H. Winchell and his collaborators at many places in Minnesota. In an earlier publication[2] McGee discussed the conglomerate to which he applied the name Rockville as probably of early glacial origin "because, first, it contains pebbles of Archean rocks which must have been brought from a distance of 200 to 400 miles, * * * and because, second, it occurs at various levels and is unstratified."

After a consideration of the characters and relationships of the several occurrences of conglomerates of the upper Mississippi Valley he concluded, in the later paper, that "on the whole, it is safe to provisionally refer the Rockville conglomerate to the Cretaceous." His considerations do not, however, prohibit their reference to Tertiary age.

In 1914 the writer, accompanied by A. O. Thomas and M. M. Leighton, examined certain low mounds a few miles southeast of Rockford, Floyd County, Iowa. Beneath the thin, sandy, and pebbly drift that covered the low swells there was exposed 1 foot to 9 feet of soft buff sandstone (in places loose sand) set full of small rounded, highly polished fossiliferous black chert and white quartz pebbles. This deposit overlies the Devonian and is clearly preglacial, for it contains no foreign material, such as the crystalline erratics in the overlying drift. Similar sand and gravel were observed in 1915 about 8 miles northeast of Osage (Liberty Township), Mitchell County, Iowa, in the SW. ¼ sec. 15, T. 99 N., R. 16 W. Polished chert and quartz pebbles of this kind are widely distributed through the drift of Iowa and Illinois.

There is thus evidence of considerable gravel in the upper Mississippi Valley before the glacial epoch. It is quite possible, however, as pointed out by Salisbury, that these various occurrences are not all of one age. Both Cretaceous and Tertiary gravels may be represented. One thing seems to be quite definite, and that is that the deposition of the gravels on the Baraboo Bluffs antedated a long period of erosion prior to the incursion of the late Pleistocene glaciers.

[1] McGee, W J, The Pleistocene history of northeastern Iowa: U. S. Geol. Survey Eleventh Ann. Rept., pt. 1, pp. 304-308, 1891.

[2] McGee, W J, Notes on the geology of a part of the Mississippi Valley: Geol. Mag., 2d ser., vol. 6, pp. 553-561, 412, 420, 1879.

CHAPTER IV.—PHYSIOGRAPHIC DEVELOPMENT AND PREGLACIAL TOPOGRAPHY.

PHYSIOGRAPHIC DEVELOPMENT.

DISSECTION OF THE ROCK SURFACE.

After the emergence of the eastern part of the area from the waters of the Devonian seas in which was deposited the Milwaukee formation the marine waters, so far as known, did not encroach upon the area of Wisconsin. During the Mississippian and Pennsylvanian time the interior sea covered large parts of neighboring States—Iowa, Illinois, and Michigan—but no deposits of this age occur in Wisconsin. The borders of this sea may have encroached upon southern and eastern Wisconsin and the deposits have been subsequently removed by erosion, but there is no evidence that such was the case. From Devonian to Cretaceous the whole region of the upper Mississippi and the Upper Great Lakes is believed to have been land and subject to denudation by erosion. Whether it stood high or low is not known.

In his correlation of the Cretaceous deposits of North America, C. A. White[1] cites the occurrence of outliers and local exposures of Cretaceous strata in Minnesota and Iowa and their possible occurrence in western Wisconsin, and says: "These discoveries indicate that the Upper Cretaceous sea extended in some places fully as far eastward as the present channel of the Mississippi River, and that it probably occupied certain adjacent portions of Wisconsin and Illinois."

With an incursion of the sea into southwestern Wisconsin would probably be associated low-level conditions of drainage throughout a large part, at least, of the area under discussion. Such low-level conditions, if long continued, would result in extensive base-leveling and only slight dissection of the land surface. The following statement of Chamberlin and Salisbury in regard to the Driftless Area of southwestern Wisconsin is probably applicable to the whole of the region under discussion:[2]

But whether submerged or not during these earlier ages the Driftless Area was probably a low-lying tract until the Tertiary age and hence was subject to but slow and slight erosion. Some denudation, however, took place previous to this age. If theoretical considerations did not force us to assert this, we should be compelled to do so by the evidence which the unconformity of the Carboniferous strata upon the earlier ones present in Illinois and Missouri, and by the manner in which the Cretaceous beds are inserted in the hollows and gorges of the Paleozoic beds in Minnesota and elsewhere. But with all these qualifications there can be little doubt that the present reliefs of the surface were mainly the work of post-Cretaceous times. The final sculpturing took place in late Tertiary or in the period of transition to the glacial period.

Attention has already been called to the probable former extension of the several rock formations over parts of the State from which they are now absent. When central Wisconsin emerged from the interior continental sea beds of limestones, sandstones, and mud shales surrounded the nucleus of crystalline rock (if, indeed, some of them did not extend completely over it) and formed an extensive plain, whose materials the run-off of falling waters at once began to carry back to the sea. Probably (see p. 93) the Niagara dolomite and perhaps all of the underlying formations down to the Lower Magnesian limestone extended over the tops of the Baraboo Bluffs, burying them under hundreds of feet of sedimentary rock, and presumably over much of the rest of the area. If this was the case hundreds of feet of rock have been removed from thousands of square miles of this area and the derived material swept southward and eastward into bordering oceans. The result was the configuration of the rock surface as exposed in the driftless part of the area and as concealed in the part mantled with the drift, except in so far as it was subsequently modified by glacial erosion. Such modification consisted probably of a general rounding and smoothing of the contours and a moderate lowering of the ridges and deepening of some of the valleys rather than of any great change such, for instance, as the excavation of new systems of deep valleys.

If the drift were stripped from the underlying rock its configuration would probably appear somewhat similar to that of the Driftless

[1] White, C. A., A review of Cretaceous formations of North America: U. S. Geol. Survey Bull. 82, pp. 142, 203–204, 1891.

[2] Chamberlin, T. C., and Salisbury, R. D., The Driftless Area of the upper Mississippi River valley: U. S. Geol. Survey Sixth Ann. Rept., p. 222, 1885.

Area. The whole area would doubtless be characterized by a mature erosion topography with large trunk valleys and branches dividing and subdividing until every square mile was dissected and thoroughly drained. The larger valleys would be found underlying in a general way the courses of the present main streams, though in many places these are wandering far from their ancestral courses. The removal of the drift would also reveal some extensive valleys which were later so well filled with drift that no postglacial stream could follow them even approximately. Although it is now impossible to picture more than the main features of this ancient preglacial topography, careful study of the present topographic and drainage relations and the correlation of the location and elevation of the rock surface where it is exposed and where it has been encountered—or failed to be encountered—in thousands of wells has enabled the writer to trace what is believed to be the location of the main preglacial valleys. The results of this study are delineated on Plate II (in pocket) by the use of hypothetical contours with an interval of 100 feet.

PENEPLAINS AND CYCLES OF EROSION.

It is not probable that the removal of this vast amount of rock and the mature dissection of the surface of the remaining deposits was accomplished in one continuous cycle of erosion. The general relations seem to indicate that at least three cycles were involved. During the first denudation the several geologic formations lay at relatively lower levels. The streams which had been dissecting the plain which emerged from the sea at length cut down nearly to the base-level determined by the sea and the master streams and then began to meander widely, swinging in broad curves to and fro across their valley bottoms, shifting their channels from place to place and cutting back the bluffs on either side, and thus broadening the valley bottoms into extensive plains and narrowing the intervening ridges to lines of isolated bluffs, many of which at last crumbled to low mounds on a nearly flat surface. The process was probably continued until the whole area was a peneplain, with but few isolated remnants of higher levels.[1]

One of these remnants, or monadnocks, protected by a heavy capping of very hard flinty rock, has survived all subsequent changes as West Blue Mound. East Blue Mound lost its protecting capping and was considerably lowered but is still one of the high points. The higher parts of the crests of the Baraboo quartzite ranges also rose above the general plain when the covering of limestones and sandstones was stripped away. The level of this plain, especially in the western half of the area, corresponds to what are now the highest uplands with elevations 1,000 to 1,200 feet above the sea, though at that time the elevation was much lower. This plain being nearly flat, beveled across the low dips of the several formations at low angles, so that it was cut in lower geologic horizons at the northwest than in the eastern and southern parts of the area. In the Lancaster-Mineral Point region the surface thus developed has been designated the Lancaster peneplain.[2]

The several limestones carry considerable chert at certain horizons, and nodules and fragments of this, being relatively insoluble, accumulated on the surface or were rounded by the streams into pebbles and transported and deposited as gravel, most of which, on further dissection, was swept away. On the surface of the south range of the Baraboo quartzite, where the exposure of the very hard quartzite retarded erosion after the mantling sediments were removed, much of this chert was left and still remains, principally west of the Devils Lake Gorge and above the 1,100 or 1,200 foot levels. Probably most of it is from the Lower Magnesian limestone, which carries much chert in masses disseminated through the rock, and from the Niagara dolomite, which, where disintegrating on the crests of the Blue Mounds, has left great masses of red and yellow flint. The highly polished river gravels found on the crest of the east bluff at Devils Lake (see pp. 99–101) were doubtless deposited about the time of the development of this peneplain.

Just to what extent this planation was carried before the process was interrupted is not known, but at length there came a general elevation of the region, so that the fall of the streams was increased and they began with renewed energy to dissect and transport the sediments to the sea. In the old valley bottoms, which had been broadened to plains, the streams began to excavate new channels and to dissect

[1] Hershey, O. H., Preglacial erosion cycles in northwestern Illinois; Am. Geologist, vol. 18, pp. 71-100, 1896.

[2] Grant, U. S., and Burchard, E. F., U. S. Geol. Survey Geol. Atlas, Lancaster-Mineral Point folio (No. 145), p. 2, 1907.

the plain with dendritic branching valleys. The work accomplished during this cycle of erosion is represented by the topography of the driftless portion of the area under discussion and by the configuration of the rock surface beneath the drift, although not all of this denudation was accomplished before another interruption took place by which the process was again accelerated. The exact time of these several events can not now be determined, but (see p. 103) it has been believed that most of the denudation was accomplished during Tertiary time.

PREGLACIAL TOPOGRAPHY.

DEVELOPMENT.

In this discussion and throughout the present paper the development of the several valleys is treated as though accomplished prior to the earliest stage of Pleistocene glaciation. Little or nothing is known, however, of conditions in southern Wisconsin when the ice first invaded the area of the United States. It is therefore quite possible that a considerable part of the deepening of the valleys and dissection of the area really occurred after the earliest glaciers had disappeared. This should be borne in mind throughout the reading of this paper and reference to "preglacial" drainage, "preglacial" topography, "preglacial" valleys, etc., should not be taken as meaning necessarily "pre-Pleistocene" drainage and topographic features. The absence of definite determination of the age of buried material lying in the valleys makes the determination of the age of the valleys themselves uncertain. The term "preglacial" as here used is meant simply to indicate that the features to which it is applied were developed prior to the incursion of the oldest ice sheet known to have invaded that part of the area.

WISCONSIN RIVER VALLEY.

ANCIENT COURSE ACROSS THE BARABOO QUARTZITE RANGES.

In preglacial time, as now, Wisconsin River was the principal stream of the region. The relations of the present stream to its ancient valley are interesting. Then as now the Baraboo quartzite ranges lay across the course of the stream and they were probably controlling factors in the development of the valley. Probably (see p. 93) when the waters of the Paleozoic seas withdrew and the sea bottom emerged as land the quartzite ridges were buried beneath hundreds of feet of marine sediments, whose surface extended as a vast featureless plain. On this plain the initial location of the stream courses was determined by the direction of the slope and minor inequalities.[1] Probably Wisconsin River followed a course directly across the buried quartzite ridges. A suggestion that Baraboo River once flowed through Devils Lake Gorge is credited to I. A. Lapham by J. H. Eaton.[2] Chamberlin in discussing the deposition of the valley drift refers to the detour of Wisconsin River about the east end of the Baraboo quartzite ranges and states:[3]

> But this does not seem to have been the course of the river in preglacial times. It appears, instead of making this detour to the eastward, to have kept on southward across the Baraboo ranges, entering the lower narrows of the Baraboo River, and finding exit through the gorge at Devils Lake, which is regarded as an old river canyon.

Doubtless initial courses were subsequently modified by warpings, elevations, or depressions in some parts of the plain more than in others, but the details of this history can not now be traced, and these factors need not be considered in this connection. The concerted work of the various streams finally so far dissected and lowered the general surface of the new-made land that some of the features now visible began to have their influence on the work of the streams. In what is now the Baraboo region a ledge of hard quartzite began to be uncovered in the bed of Wisconsin River transverse to the course of the stream. As the limestones, sandstones, and shales were worn away, the ledge, being so much harder, became more and more of an obstruction. Not improbably in places rapids and waterfalls came to be developed by the waters rushing over the crest of the hard ledge and plunging into basins worn in the softer rock below. As the top of the quartzite ledge was not straight but the rounded crest of a buried ridge, the removal of the less indurated enveloping rock would cause the stream to gradually shift its course from place

[1] An interesting discussion of the work of rain and river erosion and the development of the scenic features in the Devils Lake region is presented by Salisbury and Atwood in Wisconsin Geol. and Nat. Hist. Survey Bull. 5, ed. ser., No. 1, pp. 36-72, 1900.

[2] Report on the geology of the region about Devils Lake, Wis.: Wisconsin Acad. Sci. Trans., vol. 1, pp. 124-128, 1872.

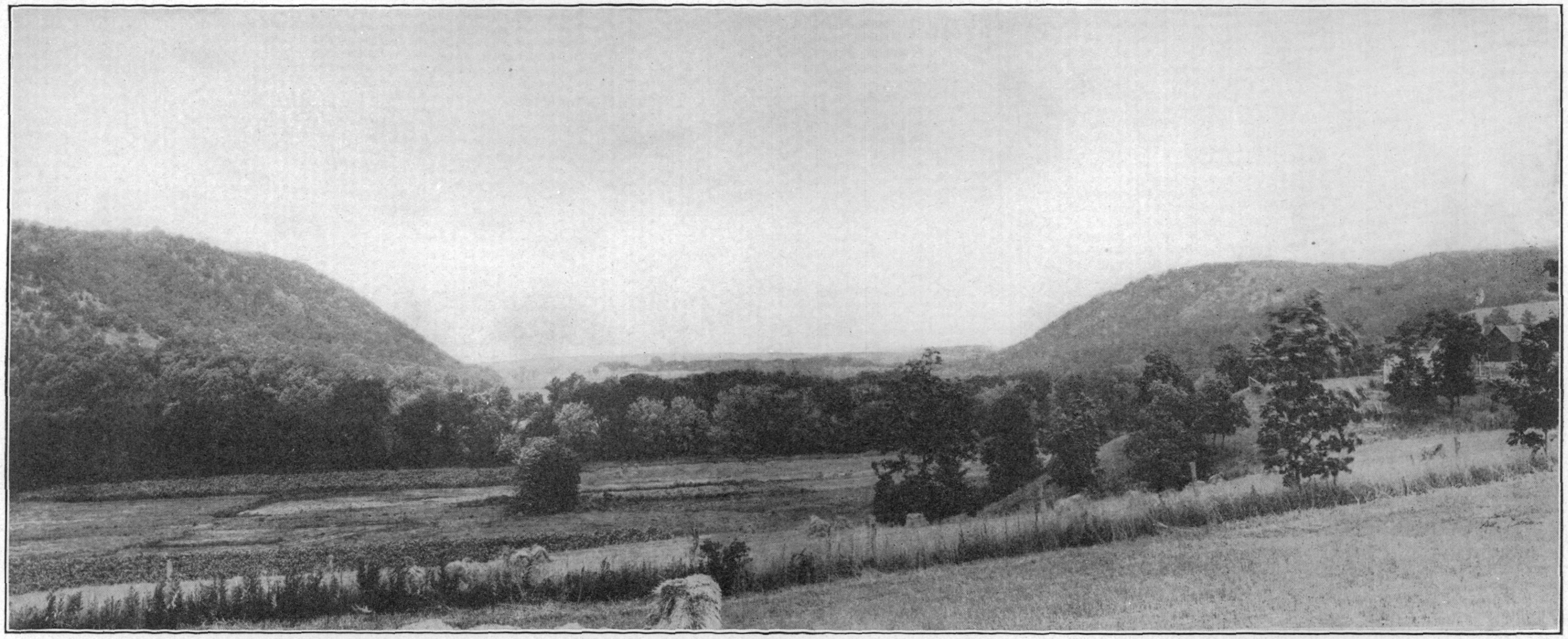
[3] Geology of Wisconsin, vol. 1, pp. 284-285, 1882.

to place until a relatively low sag in the crest of the ledge was found. Having sunk its bed in such a sag the stream would less easily shift it to another point, and the process of deepening that sag would be continued.

The structure of the quartzite ranges as exposed to-day shows them to be the remnants of great mountain folds which had suffered a vast amount of erosion prior to their submergence in the Paleozoic seas, and the relations of the sandstone remnants to the crest and slopes show that the ridge which was submerged and buried in the great accumulation of marine sands and other sediments had previously been cut by numerous ravines and gorges. Particularly is this shown in Devils Lake Gorge where, near Messingers, opposite Kirks, sandstone still remains in a recess in the wall of quartzite. A stream, shifting as indicated with the removal of the softer enveloping rock, might, in time, discover in the quartzite a notch or gorge which had been cut during pre-Paleozoic time and which had been filled during the submergence. This is what Wisconsin River appears to have done. The sag in the obstructing ledge that finally determined its location was the refilled gorge wherein now lies Devils Lake. (See Pl. VII, *B*, p. 40.) Once in this sag the stream found itself again on a sandstone bed and must have proceeded rapidly with the work of reexcavation. It is very interesting to note that there still remains on the crest of the east bluff north of Kirkland some of the ancient river gravel which was worn and rounded when the stream flowed at that level, about 800 feet higher than the present stream a few miles to the south. It is quite possible that some or all of the small potholes found pitting the quartzite at the top of the east bluff were bored into the resistant rock of the stream bed by the whirling of these same gravels in the eddies of this stream. It is certainly true that at least some of the gravel has been found reposing in these cavities.

As more and more of the Paleozoic rock was removed the south range emerged above the plain as a broad ridge through which the stream flowed in a narrow gorge. With the continued lowering of the plain another quartzite ledge was uncovered in the bed of the stream at a point 7 or 8 miles northeast of the first, where the buried crest of the lower north range was encountered. A similar process of stream adjustment located the river in the gorge now known as the Lower Narrows of Baraboo River. (See Pl. XIII.) Although the evidence that this gorge was cut in pre-Paleozoic time is not so good as that in regard to Devils Lake Gorge, the fact itself is quite possible, although the stream which first cut Devils Lake Gorge may have crossed the north range farther west, at a point where considerable thicknesses of drift and sandstone and no quartzite are now penetrated in drilling wells. So resistant is the quartzite, however, as compared with the soft friable sandstone, that it seems probable that a filled gap in the range would have been discovered and reexcavated before such a gorge as the Lower Narrows could have been cut in the quartzite, even if the main stream were so located that it could not readily change its course. The writer is thus inclined to think that the Lower Narrows, like Devils Lake Gorge, had been previously cut through the quartzite and refilled with sandstone, and that Wisconsin River in its shifting course found the filled gorge and reexcavated it. Baraboo River, coming from the northwest, joined the larger stream just north of Devils Lake Gorge and was probably joined, as now, near Ableman, by Narrows Creek. These streams repeated the process of finding buried gorges in the quartzite and reexcavating them. At least they cut gorges and, for the reasons cited above in regard to the origin of the Lower Narrows, the writer is inclined to think that they did so by reexcavating channels that had been cut by pre-Paleozoic streams and later filled with sandstone.

With the reoccupancy of the gorges the streams ceased lateral shifting at these points and devoted their energies to down cutting, and they may have increased the original depths of the gorges. This can not be determined at present, however, for no borings have reached the rock floor beneath the filling of drift. There are no deep borings at all in Devils Lake Gorge; but, on the supposition that all the depressions in the surface of the rock within the Baraboo basin and north of the ranges were drained through this outlet (no other known outlet being sufficiently deep), its bottom is believed to lie nearly 500 feet beneath the surface of the lake or not more than 500 feet above the level of the sea. It was reported to the writer that the well at Waddell's creamery, at the north outlet



LOWER NARROWS OF BARABOO RIVER.

View from the south.

of the Lower Narrows, less than 80 rods from the foot of the quartzite bluff, penetrated unconsolidated filling to a depth of 216 feet without reaching the rock bottom of the gorge—that is, to a level about 585 feet above sea level.

A well in the lower end of the Upper Narrows penetrated 85 feet of filling without reaching the rock bottom of the gorge, and numerous wells between the Narrows and Reedsburg have penetrated filling to levels equally low. The correlation of a large number of borings[1] within the Baraboo basin (see Pl. II in pocket) shows that deep buried channels lead from the Upper and Lower narrows to Devils Lake Gorge. The greatest depth of filling known to the writer to have been penetrated by these borings is 250 feet, but it is probable that beneath the terminal moraine a mile west of Baraboo there is not less than 400 feet of drift. Skillett Creek now flows northwestward over sandstone ledges in picturesque little waterfalls, but prior to the deposition of the drift it flowed eastward, joining the river south of the site of Baraboo. It is possible also that for a time, at least, Dell Creek flowed southeastward from a point now the head of Mirror Lake, traversed a valley through the north range, and joined Baraboo River south of the site of the village of Lyons. This is indicated by the southeasterly trend of the upper part of the Dell Creek valley, its abnormal present course through Mirror Lake, where the configuration of the gorge indicates that the direction of drainage has been reversed, and the presence of a considerable thickness of drift as shown by numerous wells. Mr. Fox's well on the slope north of the village of Lyons is reported to have penetrated 230 feet of drift at a point less than 80 rods south of an outcrop of quartzite, and Mr. Ruggles's well, in the northwestern part of Baraboo, is said to have penetrated 276 feet of drift. Neither of these reached rock. With the deepening of the valley north of the north range Dell Creek may have shifted eastward directly to Wisconsin River.

VALLEY BELOW THE BARABOO BLUFFS.

While this work was going on in the vicinity of the Baraboo ranges the river above and below was deepening and broadening its valley. From the outlet of Devils Lake Gorge the stream turned southwestward. So far as known to the writer there are no borings in that part of the valley between the Baraboo Bluffs and the Mississippi sufficiently deep to show the full thickness of filling, so that the depth of preglacial excavation can not be determined directly. The fall in the present stream between Portage and the Mississippi is given by Warren[2] as between 0.095 foot and 3.696 feet per mile with an average of about 1½ feet. From Merrimac to the Mississippi the total fall is about 160 feet in the distance of 108 miles, or approximately 1½ feet per mile. The fall in the ancient stream may not have been so great. If the bottom of the valley in the Devils Lake gorge was 500 feet above sea level a fall of approximately 1 foot per mile would place the junction with the Mississippi at about 400 feet above. About 40 miles below Merrimac, a mile above the mouth of a small tributary valley (Bear Creek), and more than 2 miles from the center of the Wisconsin Valley, west of Lone Rock (sec. 26, T. 9 N., R. 3 E. (Buena Vista Township), C. J. Carswell drilled a well through sand and gravel to a depth of 180 feet (540 feet above sea level) before reaching bedrock, whence it may be inferred that the rock bottom of the main valley 2 miles to the south is at a somewhat lower elevation. Several wells at Prairie du Chien, at the courthouse, the convent, and the Sacred Heart College, are stated by Herman Stookey, driller, to have penetrated sand and gravel to depths of 140 to 146 feet[3] before encountering the rock beneath the broad terrace on which the city stands. These are somewhat east of the middle line between the bluffs on either side of the Mississippi gorge at points 2 to 3 miles north of Wisconsin River. They are at one side of the present channel of the river and may not have reached the rock bottom of the valley in its deepest part. The elevation, where the rock was encountered, was about 500 feet above sea level.

The uplands on either side of the Wisconsin Valley range in elevation from 1,000 to 1,200

[1] Drill records quoted by Weidman (Wisconsin Geol. and Nat. Hist. Survey Bull. 13, pp. 78-79, 1904); also data from F. B. Clarke, A. W. Rohn, and E. W. Van Akin, drillers at Baraboo; William and James Lee, drillers at Ableman; and from owners of wells.

[2] Warren, G. K., The improvement of the water-transportation route from the Mississippi to Lake Michigan, along the Wisconsin and Fox rivers: Chief of Engineers' Ann. Rept., H. Ex. Doc. 1, 44th Cong., 2d sess., pt. 2, p. 263, 1876.

[3] See also Geology of Wisconsin, vol. 1, p. 253, 1883.

feet above the sea, and the rock formations capping these lie several hundred feet below what must have been the level of the plain which emerged from beneath the waters of the Paleozoic seas, as shown by the Niagara dolomite capping of Blue Mound with its elevation of 1,730 feet above sea level.

The relative dimensions of the valley at several points below Merrimac are shown by cross sections in figure 5; (*b*) shows the constricted character of the gorge at Devils Lake; (*c*) is drawn from the Devils Nose southward across the valley to the sandstone bluffs in (Pl. XIV, *A*) to about 2 miles at the west (fig. 5, *d*). At Bridgeport, near the mouth of the river, it has a width of less than 2 miles between the main lines of bluffs (Pl. XIV, *B*). Normally the valley of a stream widens toward its mouth. The apparently abnormal narrowing of the Wisconsin Valley is due to the fact that the westerly dip of the rock formations is greater than the fall of the stream. The development of the Lancaster peneplain cut the formations at a low angle and beveled them off (see p. 104), so that toward the center of the State the plain lay on lower geologic forma-

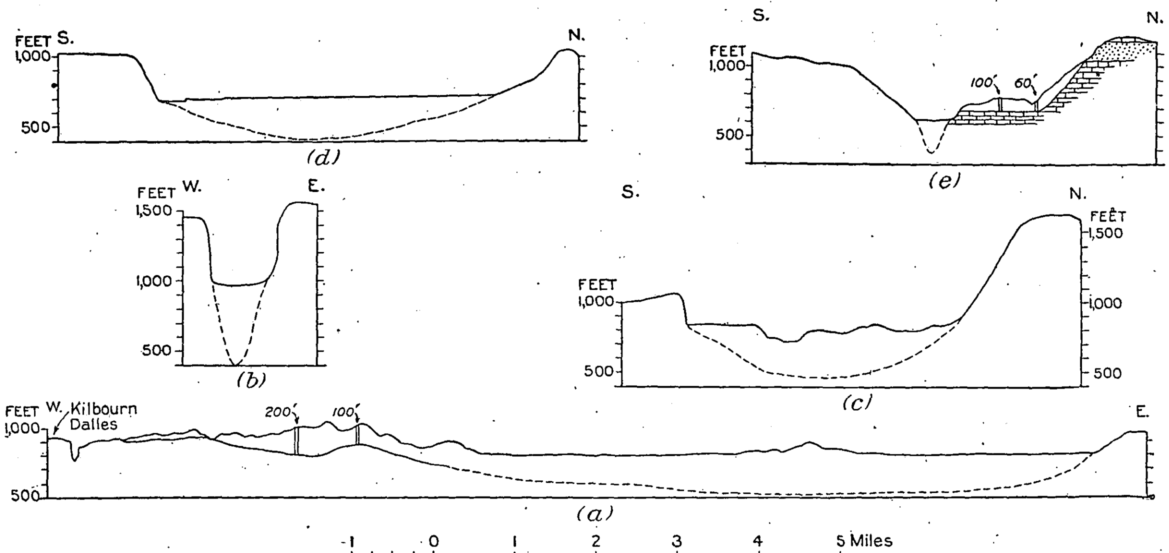
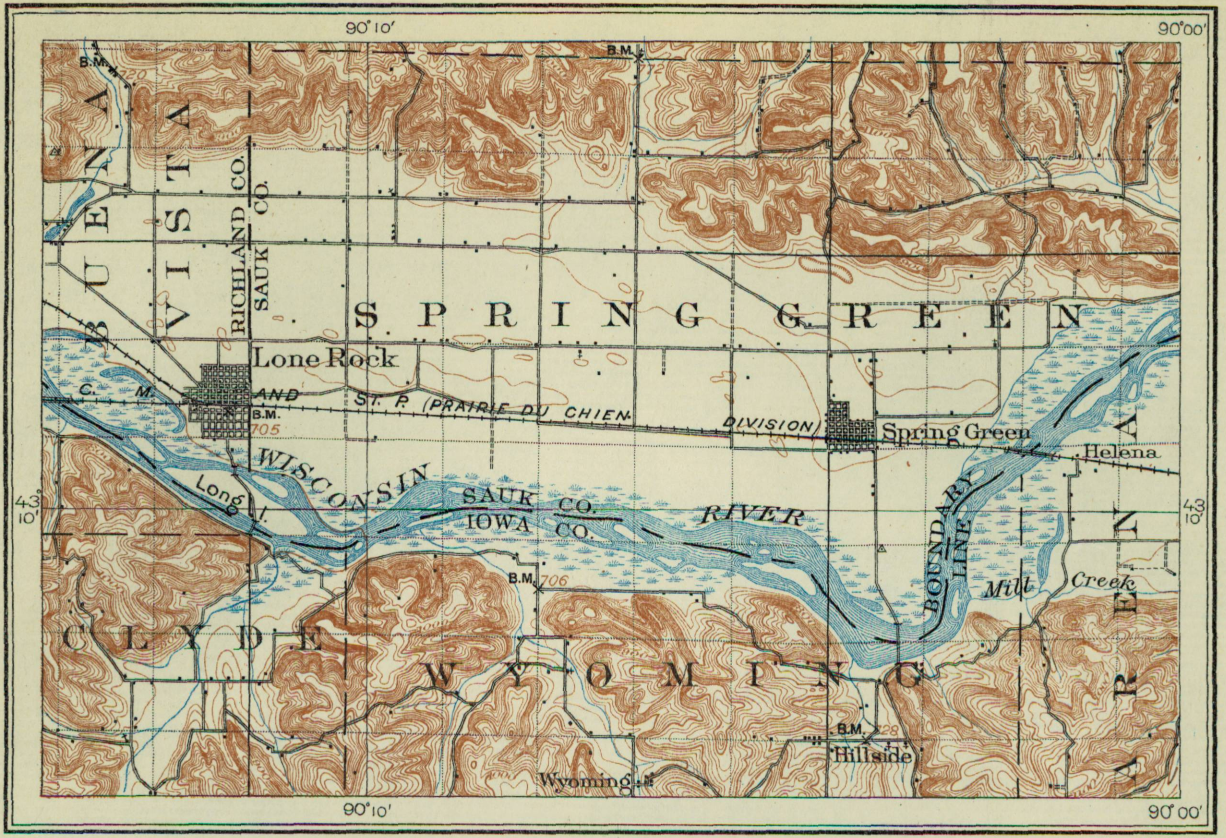


FIGURE 5.—Cross sections of present and preglacial valley of Wisconsin River. (*a*), Section on line extending eastward from The Dells at Kilbourn across the preglacial valley south of Briggsville; (*b*), Devils Lake Gorge; (*c*), section on line from Devils Nose south to sandstone bluffs in T. 10 N., R. 7 E. (West Point Township); (*d*), north-south section on line 1½ miles east of Lone Rock; (*e*), north-south section on line 1 mile west of Bridgeport.

the town of West Point. This is within the terminal moraine and there is probably 300 or 400 feet of drift filling in the valley. The upland for some distance on the south side is greatly dissected so that there are isolated bluffs of sandstone capped with Lower Magnesian limestone. Still farther south, to Black Earth Valley and beyond, the ridges coalesce into a dissected upland. West of Sauk Prairie between the river and the quartzite ranges the formations are cut into abrupt ridges with deep valleys between. One of the latter, that of Honey Creek, is shown by wells to contain 100 to 150 feet of filling in the upper part and it is probable that this thickness increases to 200 to 300 feet north of Lodi Mill.

Southward the Wisconsin Valley gradually narrows. Through the Richland Center quadrangle it narrows from about 4 miles at the east tions than it did farther out. Thus, north of the Baraboo Bluffs, the plain was on soft friable Cambrian sandstone; about the Baraboo Bluffs and to the south and southwest it lay on Lower Magnesian limestone, which was encircled by successive zones of the higher formations. When this peneplain was elevated and the stream began its dissection, Wisconsin River was either already working in the soft sandstone in the Baraboo region and to the northward or was about to cut through the limestone into it, and it readily widened its valley in this easily erodable rock. Toward the Mississippi, however, the southwesterly dip of the sandstone carried it progressively lower, leaving the less erodable limestone at the surface. Hence the valley was less readily widened and remains more constricted toward its mouth, where the limestone forms the lower parts of the bluff and what was



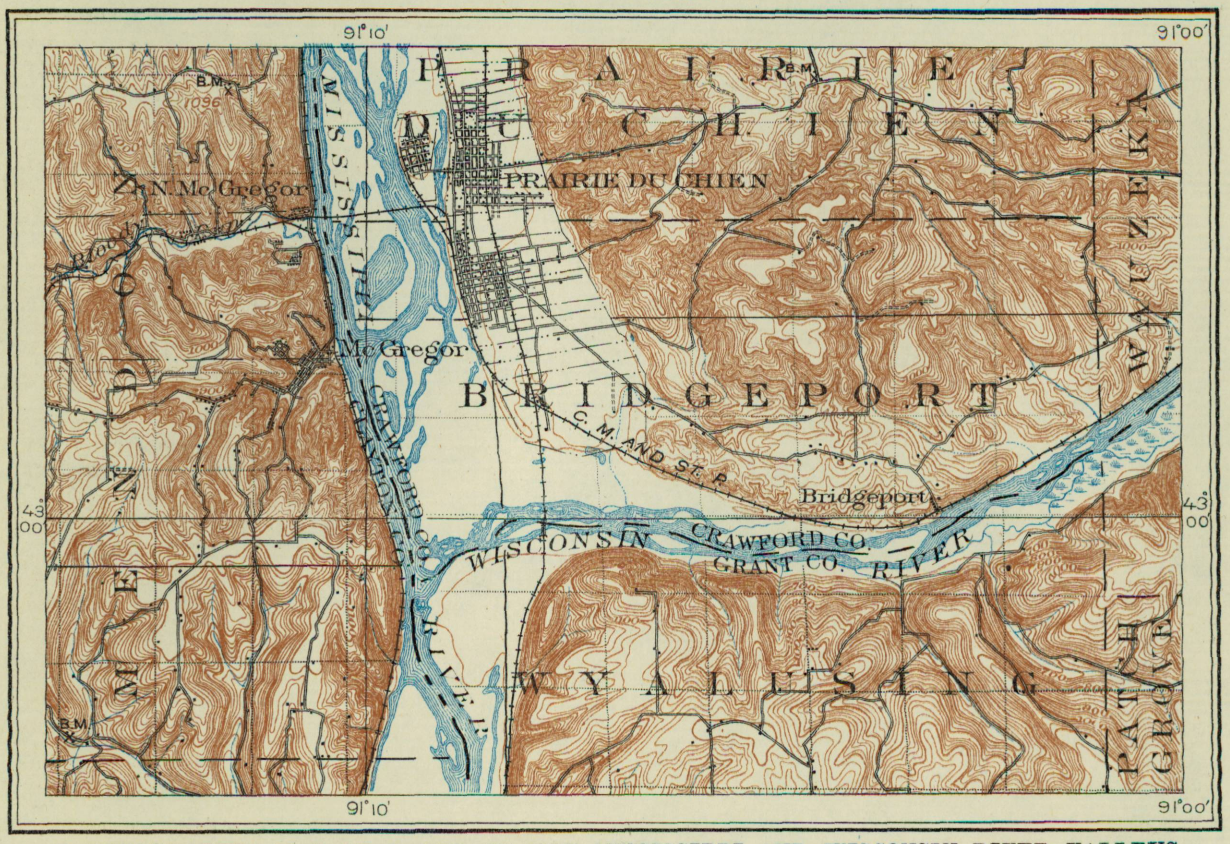
A. TOPOGRAPHIC MAP OF A PART OF THE WISCONSIN RIVER VALLEY

Scale $\frac{1}{125,000}$

1 ½ 0 1 2 3 4 5 Miles

Contour interval 20 feet.

Datum is mean sea level.



B. TOPOGRAPHIC MAP OF PARTS OF THE MISSISSIPPI AND WISCONSIN RIVER VALLEYS

Scale $\frac{1}{125,000}$

1 ½ 0 1 2 3 4 5 Miles

Contour interval 20 feet.

Datum is mean sea level.

1917

the bottom of the valley cut during the second cycle of erosion. At Bridgeport more than one-half the width of the valley, or 1 mile, is taken up by a broad terrace cut in the limestone. (See Pl. XIX, *A*, p. 170, a reproduction of a sketch in Warren's report.[1]) This rock terrace stands nearly 100 feet above the level of the stream and underlies 50 to 100 feet of much-weathered drift material mantled with loess (see fig. 5, (*e*). The present stream is thus confined to a narrow inner valley barely three-fourths of a mile in width. The elevation of the rock bottom of the Mississippi Valley at Prairie du Chien indicates at least 150 feet of filling beneath the present stream and perhaps 50 or 100 feet more. The elevation of the rock floor beneath the drift on the terrace is about 700 feet above sea level The highest elevation of the eroded surface of the drift on this terrace is 800 feet.

At Muscoda, where the river is at the north side of the valley, a sandstone ledge is exposed in the south bank at the bridge at nearly the same level. On the north side of the river for 9 or 10 miles west of Muscoda Bridge the line of bluffs is about a mile north of the river as at Bridgeport, and between the two an uneven eroded terrace of much-weathered drift mantled with loess lies from 690 to 750 feet above sea level. The writer does not know that a rock terrace underlies the drift at this place, but the ledge at Muscoda Bridge suggests that it may do so. Gen. Warren [2] states that there is sandstone in the bed of the stream 4 or 5 miles above this bridge. A small mound of sandstone is exposed at an elevation of 705 or 710 feet between the village of Lone Rock and the bridge at that place. The river flows between this rock and the south bluff, the rock and the bluff being separated by a distance of about 200 rods. This also suggests the presence of a rock terrace beneath the main filling of sand and gravel. The writer did not learn, however, that any of the wells in the village, most of which are shallow, penetrated the sandstone. Remnants of old drift terraces occur at several other points along the valley, as at Boscobel and Wauzeka, but have not been sufficiently studied to show whether or not they are underlain by rock shelves. Some of the old drift lies in the mouths of tributary valleys. (See pp. 171–172.)

The writer has not given sufficient study to the valley below Mazomanie to deduce, with much confidence, the meaning of these several rock and drift terraces, but it seems clear that the notably developed rock shelf at Bridgeport represents the bottom of the valley at one stage of erosion when the stream had cut down to base-level. The valley was then broadened to its present width by the recession of the bluffs on either side. It is possible that the development of the extensive peneplain north of the Baraboo Bluffs is to be correlated with this stage of erosion in the lower valley. Following this there must have been a general elevation of the country that caused the streams to renew the work of deepening their valleys; and in this latter cycle the reexcavation, or further deepening, of the gorges through the quartzite ranges must have been accomplished and the inner valley of Wisconsin River excavated. The inner valley bottom opposite Bridgeport is probably at least 250 feet below the top of the rock terrace.

VALLEY ABOVE THE BARABOO BLUFFS.

That the preglacial course of Wisconsin River was through the Lower Narrows and Devils Lake Gorge rather than about the east end of the quartzite range as now seems fairly certain from the conditions within the Baraboo basin and from the fact that for about 5 miles between Dekorra and Merrimac hills of easily erodable sandstone, though considerably dissected and lowered, close in on either side of the stream, narrowing the valley in some places to a width of a fraction of a mile. Warren [2] states that in the vicinity of Dekorra the sandstone which crops out on the left bank forms the river bed for some distance from the shore. A well directly west of Dekorra, beyond the stream and marsh, has penetrated 72 feet of unconsolidated material, mostly beneath marsh level; but the writer knows no other evidence of deep filling. It seems doubtful that Wisconsin River ever did flow about the eastern end of the quartzite ranges in preglacial times, for it is difficult to see how the stream once located in a valley in the friable sandstone could have been diverted to the

[1] Chief Eng. U. S. Army Ann. Rept. for 1876: 44th Cong., 2d sess , H. Ex. Doc. 1, pt. 2, vol. 2, p. 296, 1876.
[2] Idem, p. 260.

constricted gorges through the quartzite range, except by an actual blocking of the outer valley such as occurred during the glacial invasion.

North of the Baraboo Bluffs the whole aspect of the valley is different. Above the lower end of The Dells gorge the present stream is entirely out of its ancient channel. The youthful character of the gorge at The Dells is in itself an indication of this. The available records of deep wells are insufficient to show with detail and accuracy the ancient course of the stream, but the results of the correlation of such data as have been obtained are shown on Plate II (in pocket). They indicate that the last glacier crossed the ancient valley from east to west and built the outer range of morainal hills along its western margin. At many places west of the moraine isolated bluffs of sandstone, probably the last remnants of the ridges which separated adjacent valleys tributary to the main drainage line, rise above the surrounding plain, which (see pp. 226–230) is due to an extensive deposit of sand, gravel, and finer silts that filled the valleys and covered the minor inequalities. At a few places east of the outer moraine similar sandstone hills are mantled with drift. There are also other outcrops, and wells reach the rock beneath the covering of drift. Still farther east is a belt where no wells reach bedrock at depths of less than 200 to 300 feet. East of this again the rock surface rises so as to outcrop at the surface in hills and ridges or to be encountered in wells. There is thus evidence of a considerable valley buried beneath the drift. Many of the wells on the morainal ridges, though deep enough to show that the ridges themselves are entirely of drift, do not penetrate to levels much lower than the present bed of the Wisconsin. Numerous others show that the rock lies less than 700 feet above sea level, or lower than the rock terrace near the mouth of the river at Bridgeport. A few others, listed below (including a few in the Fox River valley), penetrate to still lower levels and are particularly significant.

Thicknesses of drift penetrated by wells in the preglacial Wisconsin and Fox River valleys, with elevations of the valley bottoms.

Location.	T. N.	R. E.	Sec.	Owner.	Material at bottom.	Elevation of bottom above sea level. (Feet.)	Depth of drift. (Feet.)
Lower Narrows of Baraboo (Fairfield Township).	12	7	23	Waddell Creamery	Drift	585	216
Big Spring, 1 mile north of (New Haven Township).	14	7	14	Jo Donahue	Clay	640	218
Oxford, 1½ miles southeast of	15	8	21	W. N. Johnson	Sandstone	650	190
Oxford	15	8	21	Creamery	do	660	230
Westfield, 2 miles southwest of	16	8	15	L. Kruger	"Granite"	500	360
Budsin shop (Crystal Lake Township).	17	10	28	do	Drift	580	242
Packwaukee	15	9	32	William Neal	do	600	180
Montello	15	10	......	Christ Tagatz	Sand	605	160
Lake Puckaway, north shore (Mecan Township).	15	10	20	Chicago Club	Clay	440	330

The rock surface at these places is 300 to 500 feet lower than beneath the plain in the vicinity of The Dells and an additional 200 feet lower than in the crests of the ridges and bluffs of sandstone which rise above this plain.

Two alternative inferences may be drawn from the low levels at which the rock lies at these several points. One is that they mark the bottoms of valleys that were drained by Wisconsin River or some other stream prior to the incursion of the glaciers. The other is that they mark depressions, possibly inclosed rock basins, that were deepened by glacial action, and that they are lower than the channels of preglacial streams and hence can not be regarded as evidence of the depths of the valleys between these points and the Mississippi. The hypothetical contours on Plate II (in pocket) have been drawn with the idea in mind that these low elevations mark the positions of preglacial valleys, but they allow for a certain amount of deepening by glacial action, especially in parts where the glacial movement was along the valleys rather than transverse to their courses. It certainly seems a safe inference that the bottom of the valley through Devils Lake Gorge and the Lower Narrows was as low, relatively speaking, as 500 feet above the sea, because several drill holes in the Baraboo basin west of the known limit of glaciation show that the bottom of the ancient valley there lies not higher than 600 feet above sea level; and because the well at Waddell's creamery in the north end of the Lower Narrows finds rock below 585 feet above sea level at a point where it would not be likely to have suffered much glacial abrasion.

CONCLUSIONS.

From the data in hand it appears that the preglacial course of Wisconsin River in the latitude of the south line of Waushara County lay 25 to 30 miles east of its present position, and that the stream flowed thence south-southwesterly to the Lower Narrows Gorge through a valley 6 to 15 miles wide and 300 to 400 feet deep, eroded in the Cambrian sandstone. At the Lower Narrows the valley was constricted abruptly to a gorge less than one-half mile wide and 700 to 800 feet deep. Through the Baraboo basin the valley expanded to a width of 1 to 2 miles and was again contracted at Devils Lake Gorge to a width of one-half to three-fourths mile between bold bluffs 900 to 1,000 feet or more in height. West of Merrimac the valley opened out again in the sandstone to about 5 miles. Thence southwestward the valley gradually narrowed between converging lines of bold bluffs until in the vicinity of Bridgeport, near its junction with the Mississippi, it was constricted again to a narrow inner gorge barely three-fourths mile in width. The total drainage area then included several thousand square miles, which are now drained to Lake Michigan.

TRIBUTARIES OF THE WISCONSIN VALLEY.

FOX RIVER BASIN.

It is probable that the Wisconsin Valley was joined, in the northeastern part of Marquette County, by a valley cut in the Cambrian sandstone and heading, perhaps, in the vicinity of Lake Poygan, just west of the Lower Magnesian escarpment. It is even possible that this was a through valley opening also to the east, the relations being somewhat similar to those of the present Fox and Wisconsin rivers. This, however, has not yet been satisfactorily determined. It is known from the records of a number of wells furnished to the writer by George Muttart, driller, that a buried valley 100 feet in depth (bottom, 665 feet above sea level) underlies the city of Oshkosh. A well a short distance northeast of Eureka, in the western part of Winnebago County, penetrated unconsolidated material to about the same level, but the presence of a buried channel connecting these two places has not been demonstrated.

About 6 miles north of Eureka, between Fox River and Lake Poygan, in the NW. ¼ sec. 29, T. 19 N., R. 14 E. (Poygan Township), James Lee's well is reported to have penetrated 300 feet of unconsolidated material beneath the marshy flat, or to 460 feet above the level of the sea, without encountering bedrock; and about 3 miles north of Berlin, in the NE. ¼ sec. 22, T. 18 N., R. 13 E. (Aurora Township), W. Owen is reported to have drilled 300 feet before encountering the sandstone beneath the marshy plain. The elevation of the bedrock here is not more than 475 feet above sea level.

From these and other data it seems likely that the low plain and extensive marsh tracts bordering Fox River in northern Green Lake County, southeastern Waushara County, and western Winnebago County are underlain by a considerable valley. It may be, however, that some of the depth of excavation indicated by these wells was due to gouging in the lee of the Lower Magnesian escarpment by the action of the glaciers in passing westward from the harder rock on the higher land to the softer sandstone on the lower land.

The valley in which lie Rush and Green lakes was deeper in preglacial time and was continuous westward beneath Lake Puckaway, south of Montello, and between Packwaukee and Endeavor, to a junction with the Wisconsin Valley in the town of Oxford. It may have been open through to the northeast. There is now a well-defined valley from the foot of Rush Lake to the east end of Puckaway, with ridges and uplands rising 50 to 150 feet above the lakes and marshes on either side. Several wells show 100 feet or more of drift filling in the bottom of this valley, and Green Lake has a depth of 247 feet. A well on the north shore of Lake Puckaway, at the Nee Pau Nauk clubhouse, is stated by David Brewer, driller, Berlin, to have penetrated 112 feet of sand and 218 feet of red clay without reaching the rock bottom of the valley, which here lies less than 440 feet above the sea. The direction of the last glacial advance was along this valley from northeast to southwest. That of the earlier glaciers was presumably about the same, so that it is almost necessary to suppose that the preglacial valley was deepened to some extent by the abrasive action of the ice. At three points near the south side of this valley and at Montello on the north side ledges of crystalline rock rise 350 to 650 feet above the bottom of the depression, but such rock is not known to have been exposed in the bottom of the trough. The full depth west of Green Lake is presumably in the friable Cambrian sandstone.

The marsh-bottomed valley of Grand River, which is tributary to the Fox in the southeastern part of the town of Montello, contains at least 150 feet of filling at Kingston and 60 feet or more in the vicinity of Markesan. Its trend shows that originally it must have been tributary to a valley discharging westward. The broad marsh through which Neenah Creek now flows eastward to join Fox River is underlain by a short valley which originally discharged westward to Wisconsin River. Wells show at least 100 feet of drift filling.

In the vicinity of Portage a stream occupying what is now the upper part of the Fox River valley probably flowed westward to the Wisconsin. There are now extensive marsh tracts and a low sandy plain between Pardeeville and Portage, and the amount of filling is not certainly known, though Pacham's well, 3 miles west of Pardeeville, is said to have penetrated 100 feet of drift. The courthouse well at Portage, on the north side of this ancient valley, penetrated 120 to 143 feet of drift above the sandstone, according to data from the driller and from a tube containing samples of the drillings obtained for the writer by F. T. Thwaites, who also reports that the well at the brewery one block west of the courthouse entered sandstone at a depth of 50 feet.

DUCK CREEK.

Duck Creek, heading in eastern Columbia County, flows through broad marsh tracts west of Cambria. The depth of filling beneath these marshes is not known.

DRAINAGE NEAR LODI.

Numerous wells on the low tracts among the hills west of Lodi penetrate 100 feet or more of drift, and the well of the Chicago & Northwestern Railway at Lodi is said to have passed through 194 feet of filling above the sandstone. This tract was deeply and intricately dissected.

HONEY CREEK VALLEY.

Although the glaciers did not enter the mouth of the Honey Creek valley west of Prairie du Sac, their wash filled its lower part and backed up its waters, so that a considerable filling of lacustrine and alluvial silts was deposited. The depth of the drift in the lower part of the valley is not known, but from the probable depth of that in the Wisconsin Valley it is inferred that it must be at least 300 feet. William Oxner's well in the NW. ¼ sec. 31, T. 10 N., R. 5 E. (Honey Creek Township), about 3 miles north-northwest from Blackhawk, is reported to have passed through 145 feet of unconsolidated material. Two miles farther north, near Leland, there is 100 feet of sand. One of the wells in this vicinity is said to have penetrated a bed of black muck beneath 30 feet of sand, from which it may be inferred that an interval elapsed between successive stages of filling.

HALFWAY PRAIRIE CREEK.

In the greatly dissected tract south of Sauk City, in the Cross Plains quadrangle, there are considerable amounts of filling even west of the glacial boundary, but wells reaching the rock bottoms of the valleys beneath the filling are not numerous. Several are reported as having penetrated 100 feet of filling several miles back from the Wisconsin Valley. Halfway Prairie Creek is a through valley, a sharply cut narrow col about 2 miles west of Springfield Corners connecting it with a broad valley opening eastward to the Yahara River basin northwest of Lake Mendota. That this col was open in preglacial times is uncertain but not improbable, as it is very short as well as very narrow. It may have been cut, in part at least, by glacial water, for it afforded an outlet to the Wisconsin for glacial drainage at several stages of glacial advance and retreat. On the north and south of this valley are two shorter valleys which contain somewhat less filling and whose relations are significant in the interpretation of the terraces of the Wisconsin Valley.

BLACK EARTH CREEK.

Black Earth Creek valley is another through valley, being continuous between Cross Plains and Middleton, with a valley opening eastward to the Mendota Lake basin and Yahara River. This valley was probably open clear through prior to the advent of the glaciers, but it is doubtful if any westward discharge through the col occurred before the waters from the first advance of the ice found an outlet here. The writer has no data from borings showing the actual amount of filling in this valley west of Cross Plains. Most of the wells are shallow, but the general relations to the Wisconsin Valley indicate that there is not less than 100 feet of drift at the glacial boundary at Cross Plains and that the outwashed sands and gravels reach a thickness of 250 or 300 feet in the vicinity of Mazomanie. The elevation of the upper terrace at the latter place is approximately 795 feet above sea level and the rock bottom of the adjacent Wisconsin Valley can not be more than 500 feet above, and may be considerably less. In the vicinity of what the topographic configuration indicates must have been the original parting place of the waters in this through valley, in the western part of the town of Middleton, wells penetrate 110 to 128 feet of drift, or to an elevation of 810 feet above the sea, without reaching the bottom of the ancient col. This elevation is 39 feet lower than the surface of Lake Mendota on the east and only 70 feet higher than that of Wisconsin River on the west.

TRIBUTARIES WEST OF MAZOMANIE.

No examination has been made of valleys tributary to the Wisconsin west of Mazomanie. All of those from the south, prior to the first incursion of the ice, headed about 20 miles away on the maximum heights of the area under discussion (1,200 or 1,300 feet above sea level).

ROCK RIVER VALLEY.

ROCK RIVER PROPER.

In the late Tertiary or early Pleistocene, the vicinity of Madison was occupied, not by four beautiful lakes, as at present, but by the valley of one of the tributaries of Rock River, which was then, as now, the second largest stream of the region. The distribution of the drainage lines as far south as Rockford, Ill., was the same as now in its major parts, though different in many minor details. The differences and coincidences will be most readily seen from an examination of the ancient valleys delineated on Plate II (in pocket). Between Oconomowoc and Fort Atkinson the present stream wanders far from what appears to have been its preglacial course. Near Fort Atkinson it returns and follows the ancient valley to the foot of Lake Koshkonong, then, diverted by great morainal deposits, it crosses the crests of two buried ridges and an intervening valley and reaches the ancient Yahara Valley. This it follows nearly to the junction with the ancient Rock River valley north of Janesville, where it cuts across the buried salient of the rock slope and thence continues southward to the State line, following closely the west side of the ancient valley and crossing two other buried rock salients.[1] South of the State line, nearly through Winnebago County, Ill., for 21 miles, the stream continues in the ancient valley to a point about 6 miles south of Rockford (see fig. 7, p. 153), where it meets Kishwaukee River leaves the old broad, partly filled valley and turns southwestward, reaching Mississippi River after traversing an alternating succession of narrow rock gorges and broader and more open valleys. This part of the valley is clearly postglacial,[2] the stream (flowing southwestward to the Mississippi along the retreating margin of the glacier) having established itself along a succession of small tributary valleys and across intervening cols before the ice uncovered the ancient valley. The original course of the stream is supposed to have been southward from the site of the mouth of the Kishwaukee past Davis Junction and Rochelle to the Illinois Valley below Hennepin.

From the terminal moraine north of Janesville southward nearly to Davis Junction, Ill., the old valley is 3 to 5 miles wide, and though it contains considerable filling its surface is still 100 to 200 feet below the crests of the uplands on the east and west. This relief is, however, probably not more than one-third of that which would be revealed were the drift mantle

[1] Chamberlin, T. C., and Salisbury, R. D., Preliminary paper on the Driftless Area of the upper Mississippi Valley: U. S. Geol. Survey Sixth Ann. Rept., p. 310, 1885.

[2] Leverett, Frank, The Illinois glacial lobe: U. S. Geol. Survey Mon. 38, pp. 483-493, 1899.

removed from the upland and the valley. In the following table are presented the thicknesses of the filling penetrated by numerous wells, beginning with one at Rockford, Ill., arranged in order from south to north, along the line of what appears to have been the main valley. Many of these wells which reach the bedrock are near the sides of the old valley, and the thickness of drift penetrated does not thus indicate the full depth of the filling. Furthermore, many of them stop before reaching bedrock, which thus lies at unknown depths below the bottoms. The approximate elevations above sea level of the rock in the bottom and lower slopes of the valley have been computed from the topographic maps and are indicated at the lowest points shown in various parts of the valley.

Thicknesses of drift penetrated by wells in the preglacial Rock River valley, with elevations of the valley bottom.

Location.				Owner.	Thickness of drift penetrated.	Approximate elevation of rock above sea level.	Authority.
	T. N.	*R. E.*	*Sec.*		*Feet.*	*Feet.*	
ILLINOIS.							
Rockford Township	44	1	35	Rockford Malleable Iron Works.	285	445	Record at the company's office.
Rockford, 2 miles northeast of	44	2		E. A. Kuharske	244		Owner.
WISCONSIN.							
Beloit	1	12		Beloit Water Co	125		C. P. Salmon, president of company.
Turtle Township	1	13	20, SW. ¼	Mr. Morgan	110		Julius Green, driller, Beloit.
Rock Township	2	12	15, NE. ¼	Riverside Farm	190	560	Elmer Hindes, driller, Janesville.
Laprairie Township	2	13	5, NE. ¼	Knickerbocker Ice Co.	300	520	Do.
Do	2	13	4, NE. ¼	Mr. Procter	155		Owner.
Janesville	3	12		Janesville Water Co.	241	520	Record at the company's office.
Do	3	12		Old fairgrounds	350	510	Geology of Wisconsin, vol. 2, p. 166, 1877.
Janesville Township	3	12	13, NW. ¼	Rock County Farm	253	635	Elmer Hindes, driller, Janesville.
Harmony Township	3	13	31, NE. ¼	?	150		Owner.
Do	3	13	7, W. ½	?	236		
Do	3	13	5, SW. ¼	?	190		
Milton Township	4	13	30, NE. ¼	James Craig	175		Do.
Milton Junction	4	13		Cooperative Creamery.	199	680	John Lavanway, driller, Milton Junction.
Milton Township	4	13	19, NW. ¼	John Arnold	265	615	
Do			21, SE. ¼	?	200		
Lake Koshkonong, south shore				J. H. Bingham	150	650	Owner.
Lake Koshkonong, shore				?	330	450	Chamberlin and Salisbury, U. S. Geol. Survey Sixth Ann. Rept., p. 223, 1885.
Sumner Township	5	13	16, NE. ¼	William Logie	200	580	Albert Hummel, driller, Fort Atkinson.
Koshkonong Township	5	14	6, SW. ¼	Geo. M. Hausz	250	550	Do.
Do			5, SW. ¼	Henry Ehlers	218	580	
Do			5, SE. ¼	Peter Young	*a* 204	580–	
Fort Atkinson	5	14		Charles Metzner	*a* 250	570–	Owner.
Do	5	14		Ex-Gov. Hoard	261	540	Do.
Do	5	14		Hoard's Creamery	*a* 270	510–	
Do	5	14		City	251		S. Swensen, driller, Minneapolis.
Do	5	14		Carl A. Becker	263	545	Owner.
Do	5	14		Mr. Bullock	151		Do.
Do	5	14		Fort Atkinson Brick Co.	186		Do.
Do	5	14		Dewitt Wilcox	285	525	Do.
Do	5	14		Evergreen Cemetery.	*a* 330	540–	Dewitt Wilcox, Fort Atkinson.
Koshkonong Township	5	14	35, NW. ¼	Fred Browne	210	580	Owner.
Do	5	14	35, SW. ¼	O. A. Howard	240	550	Do.
Do	5	14	1, SE. ¼	Frank Hassel	250	560	Albert Hummel, driller, Fort Atkinson.
Scuppernong Marsh, Cold Spring Township.	5	15		Mr. Blackman	*a* 270	510–	Owner.
Sullivan Township	6	16	34, NE. ¼	Oak Hill Creamery	230	570	W. Dame, Oak Hill.
Summit Township	7	17	8, NE. ¼	Mr. Peck	220	680	
Do	7	17	3, NW. ¼	P. Valentine	*a* 270	630–	
Delafield Township	7	18	19, NW. ¼	Joseph Davis	230	720	Charles Butler, driller, Delafield.
Do	7	18	12, NW. ¼	Robt. Taylor	350	650	William Larkey, driller, North Lake.
Merton Township	8	18	33, middle	Mr. Grimms	*a* 300	680–	Do.
Richfield Township	9	19	20, SE. ¼	Wm. Knuth	*a* 315	805–	Owner.
Do	9	19	21, SW. ¼	Jos. Schmidt	*a* 300	840–	
Do	9	19	15, SE. ¼	J. Hartlieb	*a* 254	825–	Do.
Do	9	19	15, NW. ¼	Herman Graf	*a* 220	880–	Do.
Polk Township	10	20	36 SW. ¼	Mr. Hoefer	*a* 137	800–	
Jackson Township	10	21	31, NW. ¼	H. Showalter	*a* 140	780–	Do.
Do	10	21	18, SE. ¼	Adam Held	130	760	Do.
Do	10	21	6, SW. ¼	Aug. Schadz	*a* 367	600–	Do.
Do	10	21	6, NW. ¼	Michael Spaeth	*a* 300	690–	Do.
Trenton Township	11	21	30, SE. ¼	Frank Bohn	198	780	
Do	11	21	22, NW. ¼	Jos. Chesak	*a* 161	740–	Do.
Do	11	21	16, NW. ¼	Matthew Hausman	*a* 220	650–	Do.
Farmington Township	12	21	34, NW. ¼	Henry Walters	200	710	Do.
Do	12	21	22, SW. ¼	George Walters	*a* 156	685–	Do.
Do	12	21	22, NE. ¼	Mr. Kirmzie	151	670	August Degner, driller, Farmington.

a Wells did not reach rock.

From the examination of the map (Pl. II, in pocket) and the consideration of the above well data, on which, together with much other data, the hypothetical contouring is based it is seen that the Rock River valley in preglacial times was a notable feature of the region.

There is some question as to the course of the main valley above Fort Atkinson. The writer is inclined to think, however, that the main valley continues eastward from Fort Atkinson, beneath the broad marshes bordering Bark River and Scuppernong Creek, to a point midway between Hebron and Palmyra, thence curves northeast and continues past Oak Hill beneath the marshes bordering Bark River between Dousman and Sullivan, thence beneath the broad gravel terraces and glacial lake basins of the Oconomowoc region. Beyond North Lake there is even more doubt as to its course. Great thicknesses of glacial drift are piled high in the bulky moraines of southwestern Washington County, and most of the wells northward to Milwaukee River east of West Bend do not reach the limestone underlying the drift, so that the line of minimum elevation can not be definitely located. Wells at Thompson, Rugby Junction, Schleisingerville near Cedar Creek, and West Bend reach the rock at elevations 200 to 300 feet above the levels reached by the Schadz, Spaeth, and Hausman wells. East of the hypothetical line of the valley indicated on Plate II (in pocket) there are numerous exposures of the rock and nearly all of the wells reach the limestone at moderate depths and at elevations 200 to 300 feet higher than the points to which the Schadz, Spaeth, and Hausman wells penetrated. There thus seems to be a limestone ridge or escarpment just east of this hypothetical valley with apparently no break through it of sufficient width to suggest an eastward discharge from a depression of such depth as is indicated by the three wells noted. The location of the margin of the Niagara dolomite in the tract north and northwest of Monches and North Lake is not known, but from the depths penetrated by wells and from the considerable troughs occupied by Oconomowoc River and its tributaries, which are mostly not due to postglacial erosion, it is inferred that a considerable depression, formed by a reentrant in the margin of the limestone, may underlie the moraines and extend northeastward into the town of Richfield. Such a reentrant would have exposed the soft underlying shale to erosion and have facilitated the extension of the valley in this direction. The level reached by the Schadz well without encountering the bedrock is as low as that reached by the Valentine well east of Oconomowoc and is about on a level with the base of the Niagara dolomite, as reported in the log of the city well at West Bend.

Possibly a narrow col of sufficient depth may have been located near the northeast corner of T. 10 N., R. 20 E. (Jackson Township), Washington County, the valley passing thence beneath the broad marshes to the northeast and southwest; but the dolomite is exposed at the surface at an elevation of 880 feet above sea level at two points barely 1¼ miles apart on either side of the col, so that the outlet, if here, must have been constricted to a width of about a mile with a depth of about 300 feet. Another possible course may have been northeastward to the Lake Michigan Basin across southern Sheboygan County. No evidence indicating such a course has been noted, but much fewer well data have been collected in this part of the area and the elevations have been less carefully compared than within the quadrangles covered by the topographic survey. It seems quite possible, therefore, that in preglacial time drainage from as far northeast as the head of Milwaukee River in southeastern Fond du Lac County and southwestern Sheboygan County may have been tributary to Rock River.

Above the bend east of Fort Atkinson the present course of Rock River seems to have little regard for the preglacial drainage lines. Between Jefferson and Fort Atkinson it crosses what was an upland tract before the deposition of the drift, at one point impinging on a limestone sill.

BURIED VALLEYS NORTHEAST OF FORT ATKINSON.

Beneath the big marsh and tamarack swamp and the hills east of Fort Atkinson lies a broad deep buried valley which must have been occupied by a considerable tributary from the north, and whose depth and location as far as Jefferson are indicated by the well data below.

Thickness of drift penetrated by wells in a valley tributary to preglacial Rock River valley.

Location.				Owner.	Thickness of drift penetrated.	Approximate elevation of rock above sea level.	Authority.
	T. N.	*R. E.*	*Sec.*		*Feet.*	*Feet.*	
Hebron Township	6	15	31, SE. ¼	Frank Florin	*a* 227	595	Albert Hummel, driller, Fort Atkinson.
Do	6	15	32, SW. ¼	Mr. Wenham	171	670	Owner's son.
Do	5	15	4, NW. ¼	Fred Mepham	125	675	Albert Hummel, driller, Fort Atkinson.
Do	6	15	19, NE. ¼	Charles Schicker	100	720	Owner.
Jefferson Township	6	15	10	M. Burkert	234	585	Do.
Do	6	14	13, NE. ¼	Gerhard Vogel	250	610	Owner's son.
Do	6	14	12, NE. ¼	Rudolph Heger	230	650	Frank Nutbaum, driller, Sun Prairie.
Do	6	14	12, NE. ¼	Parish house	288		Barney Rural, from record of driller.
Do	6	14	12, NE. ¼	Convent	300	610	Do.
Jefferson	6	14		Judge Geo. Grimm	167	734	Owner.
Do				City	200	594	Barney Rural, from record of driller.
Do				Courthouse	210		
Do				Fair grounds	184	612	

a Well did not reach rock.

Farther north the present topography gives little indication of the ancient valleys, although numerous wells show thicknesses of 100 feet or more of drift in locations which, taken in connection with the distribution of the extensive marsh tracts, indicate the presence of considerable buried troughs. In places there is evidence that the rock lies 100 feet or more beneath these marshes, but in adjacent tracts it is exposed or encountered at much higher levels. These valleys headed farther north in Dodge County. North of Horicon the trough developed in the Maquoketa shale belt may have drained northward; at least, there in no clear evidence that it drained to Rock River as now. There is evidence from the wells that from a point east of Hustisford the ancient valley may extend southeastward past Neosho and beneath the big drift hills of adjacent parts of the towns of Rubicon and Ashippun to join the main valley in the Oconomowoc region. Several of the wells penetrated 100 to 278 feet of drift, showing that the rock lies less than 665 to 745 feet above sea level, while the tops of the present hills stand 1,000 to 1,100 feet above the sea. The rock is not known to lie so low along the present course of the stream between Horicon and Ixonia, and at numerous places it is known to be higher.

CRAWFISH RIVER.

One buried valley, in the head of which lies Beaver Dam Lake, is now followed by a creek from the vicinity of Beaver Dam nearly to Lowell, then by Beaver Dam Creek to Mud Lake. Here Crawfish River comes in and follows the line to a point 5 or 6 miles south of Hubbleton, where it diverges. The ancient valley appears to pass on beneath Rock Lake southwestward to Ripley Lake and finally to join Rock River valley at Lake Koshkonong. It is reported that in constructing the grade of the Chicago & Northwestern Railway across the big marsh southwest of Rock Lake spliced piling was driven to a depth of 100 feet in the effort to obtain a firm foundation. A well at the south side of this marsh was drilled to a depth of nearly 180 feet below the marsh level without finding rock.

Preglacial Crawfish River probably continued southward past the quartzite ledges in Portland Township to the valley which contains Rock Lake and which is traceable northward nearly to Elba. Above this the Crawfish wanders around among the drumlins, its present course being almost wholly determined by the configuration of the drift.

YAHARA RIVER BASIN.

One of the most important tributaries of Rock River was the preglacial Yahara River. This stream had practically the same course as the present stream, but its valley was more capacious, as shown by the depth of drift penetrated by numerous wells. Instead of joining Rock River near the site of Fulton Center, as now, the stream continued southeastward to its junction with the main valley about 5 miles north at Janesville. The data indicate that this valley was cut down into the Cambrian sandstone throughout its entire length. It is particularly interesting in its relations to the four lakes of the Madison region, which are portions of its ancient valley, excavated in the friable Cambrian sandstone and possibly somewhat deepened and broadened by glacial erosion during the first advance of the ice. These parts received relatively less filling than somewhat more constricted intervening parts of the valley, so that when the last of the glaciers melted a series of basins were left, forming the lakes. In the last edition of Fenneman's bulletin [1] is included a section by Thwaites on the origin of Lakes Waubesa and Kegonsa and a map based on data collected by Thwaites, O. U. Stromme, and the present writer, showing the preglacial topography of the valley and the immediately surrounding region. The writer had previously prepared, as a part of his larger map, a similar but somewhat less detailed map of the region lying east of the meridian passing just east of Middleton, and he has used Thwaites's map in the revision of that portion of the map presented as Plate II (in pocket) of the present work.

It is quite possible that the valley beneath the basins of Lakes Mendota and Monona was somewhat deepened by glacial erosion. The axes of the basins lie nearly in line with the direction of the last ice movement, and that of the earlier movements was probably about the same in this region. The Cambrian sandstone is so friable that it would be particularly susceptible to erosion in such positions. Mendota Lake basin is so broad and the depth of filling penetrated by some of the wells in the immediate vicinity is so great that it is not clear just where the waters found an outlet of commensurate dimensions. The basins are separated by a buried ridge of rock 150 to 200 feet in height underlying the city. The records of a series of wells beginning with the immediate vicinity of the rock exposures near the university and extending eastward and northeastward through the city show the sandstone lying beneath 20 to 140 feet of drift but nowhere show a passage of any considerable width and of sufficient depth to have drained a depression so deep as that which lies beneath Lake Mendota. Any sufficiently deep channel must lie in a narrow interval between the borings. Thwaites thinks that it may underlie the tract between the capitol and the university, where no deep borings are known. There is a belt 1 to $1\frac{1}{4}$ miles in width about the northeast end of the city of Madison, including the marshy valley of Starkweather Creek and its north tributary in the vicinity of Elmside, in which wells are not known to reach rock. Wells at the plow and sugar factories give some indication that a deep channel may underlie this drainage line, which is in line with the broad marsh tract in the western part of Burke Township, beneath which is a deep buried valley, but it is a circuitous course to have been the main outlet of Mendota basin.

The writer was at first inclined to think that Mendota Lake basin might originally have drained westward to Wisconsin River by way of the Black Earth Valley. Study of this valley, however, shows it to be greatly constricted 3 to 4 miles west of Middleton, so that, although the full depth of the rock col is not known, it is improbable that its bottom lies lower than 200 feet above the deepest part of the Mendota basin. In his discussion of the geology of central Wisconsin, Irving [2] referred to these lake basins as probably of glacial origin and presented a map showing the parallelism between the longer axes of the lakes and the directions of the glacial movement. The depth to which the Yahara Valley was excavated in preglacial time, as has since been determined by the records of wells, was evidently unknown to him. Though referring the primary erosion of the Yahara Valley to preglacial river work the present writer is inclined to think that at least the depression beneath Lake Mendota was considerably deepened by glacial erosion in connection with the first ice advance. The records of the wells given in the table on page 118 are particularly significant of the depth and filling of the ancient Yahara Valley.

A short distance west of its junction with the Rock River valley the ancient Yahara Valley was joined by a valley from the west. As shown by the wells cited above in Porter, Union, and Brooklyn townships and by other evidence this buried valley heads in the town of Oregon and extends thence southeastward beneath the terminal moraine and bordering outwash terrace to the junction with the old Yahara Valley. About 2 miles south of Evansville a col, now traversed by Allen Creek, connected this with the Sugar River valley. Deep drift was penetrated by the Highby and Hatfield and other wells and much less thick-

[1] Fenneman, N. M., On the lakes of southeastern Wisconsin: Wisconsin Geol. and Nat. Hist. Survey Bull. 8, 2d and revised ed., pp. 37-74, 1910.

[2] Geology of Wisconsin, vol. 2, pp. 422 and 612, pl. 26, *A*, 1877.

nesses by neighboring wells, indicating that the ridge which extends northwest from Evansville must have been cut by deep ravines.

(Rock Township), 187 feet in its lower part. A creek flows in the broad bottom on the filling of the next valley, but in sec. 16 it leaves the

Thickness of drift penetrated by wells in preglacial Yahara Valley and tributary valleys.

Location.	T. N.	R. E.	Sec.	Owner.	Thickness of drift penetrated.	Approximate elevation of rock above sea level.	Authority.
					Feet.	Feet.	
Middleton Township	7	8	7, S. ½	?	[a] 110	810—	
Do	7	8	8, SE. ¼	John Luth	[a] 128	810—	Owner.
Do	7	8	9, SW. ¼	Fritz Hausman	[a] 126	825—	
Do	7	8	2, SW. ¼	John Schroeder	226	700	W. J. Schneider, driller, Middleton.
Do	7	8	11	Middleton post office.	133	810	Do.
Do	7	8	11, SE. ¼	?	[a] 180	740—	
Do	7	8	12, SE. ¼	M. Durkopf	[a] 201	740—	Owner.
Westport Township	8	9	34	On island	[a] 140	710—	W. Haak, driller, Madison.
Madison Township	7	9	16, SW. ¼	L. Post	240	660	Do.
Do	7	9		Science Hall, Univ. Wisconsin.	100	780	F. T. Thwaites.
Do	7	9		Brewery	140	730?	Do.
Do	7	9		Capitol	126	800	Geology of Wisconsin, vol. 2, p. 50, 1877.
Do	7	9	25, NW. ¼	Sanitarium	130	740	F. T. Thwaites.
Burke Township	8	10	30, NE. ¼	H. Stoppelworth	[a] 280	640—	
Blooming Grove Township	7	10	6, NE. ¼	Dexter Curtis	313	550	Mr. Eastman, driller, Madison. The lower 100 feet is in clean sand which may be a very loose friable sandstone.
Do	7	10	5, SW. ¼	Plow factory	[a] 150	700—	F. T. Thwaites.
Do	7	10	5, SE. ¼	Sugar factory	200	650?	Do.
Do	7	10	30, middle	?	200	660	
Do	7	10	32, SW. ¼	Mr. Libby	[a] 100	780—	
Do	7	10	31, SE. ¼	Mr. Welch	[a] 140	730—	
Fitchburg Township	6	9	9, SE. ¼	W. Sikes	[a] 178	770—	Owner.
Do	6	9	10, NW. ¼	D. Larkin	[a] 150	750—	Do.
Do	6	9	1, SE. ¼	Mr. Uphoff	[a] 262	620—	
Dunn Township	6	10	McFarland	Oscar Johnson	140	730	Do.
Do	6	10	9, SW. ¼	W. L. Ames	[a] 135	710—	Do.
Do	6	10	9, NE. ¼	S. Thompson	[a] 120	770—	Do.
Do	6	10	10, NW. ¼	E. Johnson	[a] 100	780—	Do.
Do	6	10	15, NE. ¼	?	[a] 118	750—	F. T. Thwaites.
Do	6	10	36, SE. ¼	P. Tibbit	186	775	
Pleasant Spring Township	6	11	29, NW. ¼	Mr. Nichols	[a] 125	745—	
Do	6	11	32, NE. ¼	?	[a] 147	735—	
Dunkirk Township	5	11	5, SE. ¼	City of Stoughton	201	640	P. C. Miller, of J. P. Miller Artesian Well Co., Chicago, Ill.
Do	5	11	10, SE. ¼	?	140	760	
Do	5	11	28, NW. ¼	Mr. Downer	[a] 250	660—	Owner.
Do	5	11	32, SE. ¼	Mr. Attlesey	[a] 211	670—	Do.
Porter Township	4	11	2, SE. ¼	J. J. Spike	[a] 217	665—	Do.
Do	4	11	3, NW. ¼	Mr. Sweeney	[a] 206	695—	Do.
Do	4	11	11, NW. ¼	Mr. Nelson	[a] 273	600—	Do.
Do	4	11	11, NE. ¼	Mr. Pomeroy	107	....	Do.
Do	4	11	12	Mr. Genson	130	....	Do.
Do	4	11	12	Mr. Gardiner	125	....	Do.
Do	4	11	14, SW. ¼	E. S. Raymond	[a] 230	650—	Do.
Do	4	11	23, NE. ¼	John Peach	151	715	Do.
Do	4	11	25, SE. ¼	Mr. Stewart	146	730	
Fulton Township	4	12	8, SE. ¼	?	[a] 193	650—	
Do	4	12	8, SW. ¼	Mr. Post	172	....	Do.
Do	4	12	18, SW. ¼	Mr. Hoffman	[a] 150	650—	Do.
Do	4	12	20, SW. ¼	Douglas Hopkins	[a] 240	600—	Do.
Do	4	12	33, NW. ¼	Wm. Hencky	200	700	Do.
Porter Township	4	11	33, S. ½	Mr. Stevens	[a] 150	770—	Do.
Do	4	11	31, NE. ¼	E. S. Griffith	[a] 190	750—	Do.
Union Township	4	10	17, NE. ¼	F. Burgess	[a] 100	860—	Do.
Do	4	10	15, SW. ¼	E. B. Hubbard	[a] 175	755—	Do.
Do	4	10	22, NE. ¼	Edgar Smith	[a] 140	840—	Do.
Do	4	10	14, NE. ¼	?	[a] 148	770—	
Do	4	10	28, NW. ¼	Mr. Highby	175	775	Do.
Do	4	10	29, NW. ¼	W. E. Hatfield	174	835—	Do.
Brooklyn Township	4	9	1, NE. ¼	Mr. Sargent	[a] 168	810—	W. H. Marks, Brooklyn.

[a] Wells did not reach rock.

WESTERN TRIBUTARIES OF ROCK RIVER IN JANESVILLE-BELOIT REGION.

Several small valleys joined the Rock River valley from the west between Janesville and Beloit. The first, 1 to 2 miles west of Janesville, contains 80 feet or more of drift in its upper part, and according to W. R. Kilmer's well in the NE. ¼ sec. 10, T. 2 N., R. 12 E.

line of the old valley and flows over a limestone bed. Within less than a mile north and west of this rock exposure wells show the location of the ancient channel. That of John O'Lary, in the SE. ¼ sec. 8, penetrated 160 feet of drift over St. Peter sandstone, and that of C. H. Hayner passed through 217 to 218 feet of sand and clay to Lower Magnesian limestone. A third well midway between Mr. Hayner's and

Mr. Kilmer's penetrated 145 feet of drift over sandstone. The Riverside farm well (p. 114) is near the south side of the mouth of this ancient valley and just across the river, barely 80 rods from a point where the Trenton limestone is exposed in a railway cut, yet it was drilled through 190 feet of drift to the Lower Magnesian limestone. Another well 80 rods southwest of the same exposure of limestone passed through 160 feet of drift to sandstone. One-half mile southeast of the latter well Trenton limestone is again exposed on both sides of the river. This illustrates well the difference in detail between the ancient and the present topography. Here was a limestone-capped ridge 200 feet or more in height terminating in two narrow salients between which was a deep ravine and on either side of which were capacious valleys; and to the east was the great valley of Rock River with its bottom 300 to 400 feet below the ridge crest.

Bass Creek valley is broad and contains an extensive marsh tract, through which the present stream meanders. No wells are known to penetrate the entire filling (probably 250 to 300 feet) in the lower part of this valley. J. C. Green, driller, Beloit, informed the writer that a well drilled on the flat southeast of Hanover did not reach the rock at a depth of 165 feet. Several wells on the slopes north of the marsh are said to have been drilled to depths of 100 to 175 feet without reaching rock.

Two miles east of Footville the ancestral valley of Stevens Creek is blocked by a great deposit of drift, and the present stream flows along the north and east sides of the old valley. In the south part of sec. 27, T. 3 N., R. 11 E. (Center Township), it has cut a small gorge in limestone and at several other points it is close to the limestone. About 80 rods southwest of the rock gorge Henry Drafahl's well is said to have passed through 140 feet of drift without reaching rock; another well about a mile farther southeast, near the west side of the old valley, shows 100 feet of drift over St. Peter sandstone. The maximum depth of filling is not known.

The village of Orford stands on the site of a big drift fill which forms the divide between one branch of Stevens Creek valley and Sugar River valley. Three wells in this village were reported to the writer as penetrating 132 to 160 feet of drift without reaching the rock bottom of the ancient col. The well at Clemetson's store entered sandstone at a depth of 128 feet. It was also said that Clemetson's well near the road northwest of the village passed through 200 feet of drift, and that Edward Egan's well on the hill to the north did not reach rock at the depth of 212 feet. The original divide was probably at the narrow col 2 miles west of Orford.

EASTERN TRIBUTARIES OF ROCK RIVER IN KOSHKONONG-BELOIT REGION.

Several short valleys were tributary to Rock River valley from the east. One of these, in T. 5 N., R. 14 E. (Koshkonong Township), is indicated by the thickness of drift penetrated by three wells—at South Koshkonong Creamery (SE. ¼ sec. 28), 112 feet; at H. Farnsworth's farm (NW. ¼ sec. 21), 200 feet; and at John Menogue's place (SW. ¼ sec. 16), 201 feet (without reaching rock).

Another tributary whose course has not been traced very satisfactorily appears to join the main valley in the vicinity of Milton Junction.

A third eastern tributary underlies the plain south of the morainal hills in southeastern Harmony and southern Johnstown townships, but the rock surface rises to the east, so that this valley can hardly be more than 6 or 8 miles long. It may head in a col or sag in the crest of the rock upland to the east.

A fourth branch probably underlies the plain north of Shopiere, in La Prairie and Turtle townships. Two wells on this plain were reported as penetrating 120 feet of drift each, and the drift-clad rock slopes of the upland on the north and south open out broadly to the west; to the east, however, they close up rapidly, so that within 5 miles of the main valley, this lateral reentrant heads in the narrow postglacial gorge traversed by Turtle Creek. This branch thus appears to have been short and broad.

PECATONICA AND SUGAR RIVER BASINS.

TRIBUTARIES.

Four miles southwest of Beloit, in the vicinity of Rockton, Ill., Rock River is joined by Pecatonica River, which meanders through a broad valley plain that evidently marks the course of a much deeper preglacial valley. Only a small part of the Pecatonica Valley has been examined by the writer, but considerable study has been given to the tributaries within the drift-covered part of southern Wisconsin.

COON CREEK.

Coon Creek crosses the State line 6 to 7 miles west of Beloit. The ancient valley of this stream was broad and contains considerable filling. One and one-half miles south of the State line in the NW. ¼ sec. 9, T. 44 N., R. 1 E. (Rockton Township), two wells show the location of this valley, although the present surface is nearly flat. D. N. Grant's well penetrated 128 feet of drift without reaching the rock and W. C. Johnson's well entered the St. Peter sandstone at the depth of 140 feet. Within a mile west of these wells Trenton limestone is exposed in the road. One mile north of the State line the well at the creamery in the SE. ¼ sec. 27, T. 1 N., R. 11 E. (Newark Township), did not reach rock at 110 feet, and 3 miles northwest up the valley J. A. Matthew's well is said to have passed through 244 feet of drift before it cut the sandstone. The accuracy of this statement, however, is not vouched for, although there seems no good reason for doubting it. An ancient tributary of this valley is so blocked with drift in the northwestern part of sec. 26 (Newark Township) that the present drainage has been diverted to one side and has cut a channel through the limestone, though a well shows at least 160 feet of drift in the original course of the stream.

SUGAR RIVER BASIN.

For several miles north and south of the State line Sugar River meanders through a broad marsh tract, beneath which there is undoubtedly 200 feet of filling and perhaps considerably more. This puts the bottom of the ancient valley about 400 feet below the level of the crests of the rock ridges on either side in Wisconsin. Two miles south of the State line, where the road crosses the marsh in the western part of Shirland Township, these crests are about 1½ miles apart. Toward the north the valley broadens as the sandstone rises higher in what was the zone of erosion, so that the rock slopes rising from opposite sides of the present valley plain in Wisconsin are 3 to 5 miles or more apart.

North of the site of Brodhead the removal of the St. Peter sandstone from the uneven surface of the Lower Magnesian limestone seems to have left some ridges of the latter rock standing in the midst of the broad valley, so that the drainage must have been divided into several channels. This is inferred from the fact that in places rock is at or near the surface and in other places wells penetrate considerable thicknesses of drift. North of Albany hills of Lower Magnesian limestone rise above the valley plain with St. Peter sandstone ledges outcropping about their slopes. About 2 miles north of Albany an east-west line of warping or faulting extends from Monticello to the Rock River valley, if not farther to the east and west. North of this line the base of the Trenton limestone has been depressed to levels 50 to 150 feet lower than the base of the same formation south of the line of displacement. Along this line, which may have been one of considerable fracturing, as is indicated by the fractured and recemented condition of the St. Peter sandstone exposed in the north part of sec. 7, T. 3 N., R. 10 E. (Magnolia Township), were developed the valleys now occupied by Little Sugar River and Allen and Marsh creeks. The lowering of the Trenton limestone caused narrowing of the Sugar River valley in the northern part of T. 3 N., R. 9 E. (Albany Township), but farther north as the limestone again rises the valley again widens out in the sandstone. Where the Lower Magnesian limestone rose again into the zone of erosion, the removal of the sandstone from its uneven surface repeats the anomalous conditions seen farther south. Low swells or ridges in places rise in the midst of the valley plain and constrictions of the valley bottom in places simulate the conditions due to obstructions of glacial drift.

In a few places thick deposits of drift have caused the abandonment of the preglacial valleys by the postglacial streams. About a mile west of Dayton, for instance, a filling of 100 feet or more of drift has obliterated the ancient valley, and the present stream turns northward and cuts through the sandstone beside the railway a mile south of Belleville. A similar obstruction of drift has caused a shifting of the present drainage over a limestone ledge in the southern part of sec. 2, T. 2 N., R. 7 E. (Sylvester Township). This is shown by the topography and not by well records. The lower part of the former valley of Jordan Creek is obstructed by a big filling of drift 1 to 4 miles northwest of Brodhead. The present stream drains the basin through a sharp ravine cut in the sandstone bottom of a sag in the rim of the basin in the NE. ¼ sec. 16, T. 2 N., R. 9 E. (Decatur Township). The wells show at least 175 feet of drift in the lower part of the old valley. At the head of the valley in which stands the village of Juda a narrow gorge, about 20 rods in width at the bottom and 30 to 40 feet in depth, eroded in the Trenton limestone, is traversed by the railway and connects to the west with a tributary of Richland Creek. This rather unusual feature may not have existed, at least with its present dimensions, prior to the advent of the first glacier. It probably served as an outlet to the Pecatonica Valley for glacial waters ponded in the Sugar River valley during both the advance and retreat of the ice front, being enlarged if not originally cut by such waters passing through it.

Thicknesses of drift penetrated by wells in the Sugar River valley and tributary valleys.

Location.	T. N.	R. E.	Sec.	Owner.	Thickness of drift penetrated.	Approximate elevation of rock above sea level.	Authority.
					Feet.	Feet.	
Exeter Township	4	8	10, SE. ¼	?	a 115		
Do	4	8	15, NE. ¼	?	a 60		
Do	4	8	15, NW. ¼	Mr. Morse	130		Owner.
Do	4	8	23, NW. ¼	Jos. Dunbar	80		Do.
Attica	4	9		?	a 100	730−	
Albany Township	3	9	8, NW. ¼	?	125	725	
Decatur Township	2	9	1, SE. ¼	Mr. Wheeler	a 105	715−	Do.
Do	2	9	2, NE. ¼	Louis Kamerer	150	700	Do.
Do	2	9	12, NE. ¼	S. E. Schliem	164	655−	Do.
Do	2	9	19, SE. ¼	H. E. Bernstein	120	730	Do.
Do	2	9	20, NE. ¼	Mr. Hooker	a 104	735−	Do.
Do	2	9	20, SE. ¼	H. E. Schrader	112	740	Do.
Do	2	9	25	City of Brodhead	138	655	Log and samples preserved by William Roantree and R. Broughton, M. D., Monroe.
Do	2	9	27, NE. ¼	?	a 175	690−	
Do	2	9	27, NW. ¼	Mrs. A. J. B. Fleck	168	670	Owner.
Do	2	9	30, NE. ¼	Mr. Fleck	150	710	Do.
Spring Valley	2	10	19, SW. ¼	Brodhead Cemetery	135	660	William Roantree.
Avon Township	1	10	30, NW. ¼		128	650	
Do	1	10	29. SW. ¼	Schoolhouse	175?	600−	

a Does not reach rock.

DRIFTLESS AREA.

Outside the limit of glaciation, within the Driftless Area, there is probably but little difference between the present topography and that which existed prior to the first incursion of the ice. A certain amount of deepening of the valleys and perhaps considerable dissection of the slopes have been accomplished by erosion during this long time, and the crests and slopes have been mantled with a coating of loess of variable thickness, but the general aspect is probably much the same. No detailed examination of that part of the Driftless Area south of Wisconsin River and more than 5 or 10 miles beyond the margin of the drift has been made by the writer. In the Pecatonica Valley above the drift dam there is probably 50 to 100 feet of glacio-lacustrine and alluvial filling.

EAST BRANCH OF PECATONICA RIVER.

Midway between Browntown and Martintown in sec. 21, T. 1 N., R. 6 E. (Cadiz Township), the valley, which immediately to the north has a width of nearly a mile, is obstructed by a great deposit of glacial drift. The stream has cut a narrow gorge at the west side through the drift and into the limestone. Two miles farther south on the State line just west of Martintown the valley is again obstructed by a similar deposit. Here the stream swings to the east side of the valley and has eroded a narrow new channel. The records of the following wells show the thickness of the drift in these two obstructions:

Thicknesses of drift penetrated by wells in Pecatonica River valley and Honey Creek valley.

Location.	T. N.	R. E.	Sec.	Owner.	Thickness of drift penetrated.	Approximate elevation of rock above sea level.
					Feet.	Feet.
Cadiz Township, Wis.	1	6	21, NE. ¼	John Meachim	*a* 100	740—
Do	1	6	21, NE. ¼	?	*a* 75	725—
Do	1	6	21, SE. ¼	J. P. Lynch	180	660
Do	1	6	21, SW. ¼	T. A. Lynch	*a* 110	750—
Do	1	6	21, SW. ¼	do	60	740
Do	1	6	24, SE. ¼	Henry Bartlett	*a* 85	
Clarno Township, Wis.	1	7	18, SE. ¼	?	*a* 80	
Do	1	7	19, NW. ¼	Mr. Truman	*a* 63	
Winslow Township, Ill.			16	Mr. Dittmar	*a* 65	755—

a Does not reach rock.

The three wells last cited show the thickness of drift in Honey Creek valley in the western part of T. 1 N., R. 7 E. (Clarno Township). The creek has been diverted to the southeast side of the valley and has cut small gorges in the limestone at three points in sec. 19. A small dam of drift obstructs the valley of Spafford Creek in sec. 33, T. 1 N., R. 5 E. (Wayne Township), where the stream is crowded to the west side of the valley. Wells near the south side of the Pecatonica Valley at Freeport, Ill., are stated by Hershey [1] to have penetrated 100 feet of drift before reaching rock.

PREGLACIAL TROY VALLEY.

In 1904, in discussing the preglacial topography of a portion of southeastern Wisconsin,[2] the writer described what he believed to be a considerable buried valley east of Rock River valley and just west of the margin of the Niagara dolomite in Walworth County, where the removal of the protecting cap of dolomite must have exposed the soft underlying shale to erosion such as occurred farther north in Dodge and Fond du Lac counties. The hypothetical location and dimensions of this valley were shown by contour lines which are reproduced with slight changes on Plate II (in pocket) of the present paper. As was indicated in the description the data on which this mapping is based are not entirely conclusive, but, after consideration, the writer is inclined to think the evidence is in favor of its substantial accuracy. It should of course be clearly understood that the configuration shown is largely hypothetical and can be demonstrated only by the sinking of deep wells or other drill holes in the belt between Delavan and Lauderdale lakes. The buried valley, which lies east of the preglacial Rock River valley and is separated from it by a broad, drift-covered ridge of dolomite, probably owes its location to the relative softness of the Maquoketa shale. The upper branches of this ancient valley are traversed by Fox River between Waukesha and Big Bend, but the main valley contains no stream of any importance. As the position of this buried valley is most plainly marked by the low area within and adjacent to the towns of Troy and East Troy in northeastern Walworth County it has been found convenient to designate this preglacial trough the Troy Valley.

Although the Troy Valley in adjacent parts of Waukesha and Walworth counties lies 100 to 200 feet lower than the uplands on the north and south, it is so largely filled with drift and its surface is so peculiar topographically that it scarcely appears to mark the position of a definite river valley. It is a plain above which rise a few small undulating areas and in which are many irregular depressions of large and small extent (varying from 10 to 100 feet), bordered by abrupt gravel slopes and occupied by marshy tracts and by more than a score of ponds and lakelets.

The records of several wells, however, show that this basin marks the position of a preglacial valley cut through the marginal beds of Niagara dolomite and Maquoketa shale. In Fred-

[1] Hershey, O. H., Preglacial erosion cycles in northwestern Illinois: Am. Geologist, vol. 18, p. 84, August, 1896.

[2] Alden, W. C., The Delavan lobe of the Lake Michigan Glacier of the Wisconsin stage of glaciation and associated phenomena: U. S. Geol. Survey Prof. Paper 34, pp. 16-18, pl. 2, 1904.

Andrew's well about 7 miles east of the southwest corner of Waukesha County, not far from the village of Mukwonago, drift was penetrated to a depth of 300 feet, the first rock, Maquoketa shale, being reached at an elevation of 540 feet above the sea. About $4\frac{1}{4}$ miles southwest of Mr. Andrew's well near the village of East Troy, Stephen Field's well penetrated 330 feet of drift, reaching the Galena dolomite at an elevation about 530 feet above sea level. About $1\frac{1}{2}$ miles southeast of County Lake in the town of Troy, 6 miles west of Mr. Field's well, McKee Bros.' well penetrated 401 feet of drift before reaching rock at an elevation of 480 feet above sea level.[1] From these well records it is clear that there is in this locality a very considerable preglacial valley. The position of its outlet is, however, somewhat conjectural. The valley appears to be too deep to have discharged into the Rock River valley by the way of the valley between Palmyra and Fort Atkinson; moreover, the limestone has been reached at a sufficient number of points beneath the Kettle moraine and outwash deposits to make it almost certain that a rock ridge 200 to 300 feet high separates the two troughs. Like reasons appear to exclude connection with any of the valleys tributary to the ancient Rock River valley in eastern Rock County. Neither does it seem probable that there was an eastward discharge to the basin of Lake Michigan. The most probable line of discharge is southward through Walworth County just west of the west margin of the Niagara dolomite, but this mapping is based on the general relations rather than on any decisive evidence furnished by the area itself. A well 3 to 4 miles southeast of the village of Darien is said to have penetrated 150 feet of clay and 250 feet of gravel without reaching rock. This report was not verified, but if it is correct the rock lies below an elevation of 600 feet above sea level at a point 2 to 3 miles west of the axis of the valley as projected.

The city well at Elkhorn entered the Maquoketa shale at a depth of 213 feet without encountering any overlying Niagara dolomite, showing that the west margin of the latter formation lies east of that place. The removal of the protecting dolomite must have exposed the underlying soft shale to extensive erosion in the region just west of Elkhorn, as it did farther north in the towns of Troy and East Troy. That the shale was so eroded in the Lake Geneva basin is shown by the record of the well drilled at the Yerkes Observatory, near the northwest shore of the lake. This well penetrated 405 feet of drift before reaching the shale at an elevation of 588 feet above the sea. Though the shale is commonly 200 feet or more in thickness, 177 feet being penetrated by the Elkhorn well, only 33 feet was found overlying the Galena dolomite at this point. It thus appears probable that the course of Troy Valley is that shown on Plate II (in pocket).

From the head of Sugar Creek southward to Lake Geneva the present topography gives no indication of such a buried valley. The surface is gently undulating and ranges in elevation from 900 to 1,080 feet. If this be the real course of the valley, and there seems little reason to doubt that it is, there must be 400 to 600 feet of drift piled into it within the limits of the Darien moraine.[2]

The further extension of the Troy Valley is doubtless to be found extending beneath Bigfoot Prairie southward through the western part of McHenry County, Ill., just west of Harvard, and thence down Rush Creek valley to the Kishwaukee. Swinging westward into Boone County, Ill., it continues past Belvidere to the junction of the north and south branches of Kishwaukee River in Cherry Valley Township, south Winnebago County, Ill., where it terminates abruptly, and the united stream enters a constricted valley cut in the limestone. (See fig. 7, p. 153.)

Referring to the preglacial course of the Kishwaukee, Leverett[3] says:

> The Kishwaukee River, the first important eastern tributary of Rock River south of the Wisconsin line, is in a new course for a few miles below the junction of the north and south branches. It is not clear whether the old mouth was a short distance north of the present mouth or whether the stream passed southward up the south branch to the vicinity of Fielding and thence across to the old Rock River valley near Esmond. The north and

[1] Authorities for well records: Andrew's well, Otto Hembrook, driller, Mukwonago, Wis. Field's well, samples of drillings in the possession of Mr. Arthur Smith, Burlington, Wis. McKee Bros.' well, W. L. Thorne, driller, Whitewater, Wis. It is quite possible that the rock reached in McKee Bros.' well is the Trenton limestone, but so meager are the data that the writer has not indicated the Galena dolomite as cut away along the line of this valley on the areal-geology map.

[2] Since the above was written, certain data have come to light strongly confirming the writer's interpretation. In 1915 a well was drilled by F. M. Gray for the Bradley Knitting Co. at Delavan. According to the log furnished by F. T. Thwaites, who examined samples of the drillings, bedrock was first encountered beneath 415 feet of gravel, till, and sand at an elevation of about 485 feet above sea level. The only change in the mapping of the buried valley necessitated by this record is the shifting of the 500 and 600 foot contours somewhat farther west than their location on the earlier map. This change has been made on Plate II (in pocket) of the present paper.

[3] The Illinois glacial lobe: U. S Geol. Survey Mon. 38, p. 485, 1899.

south branches each occupy a preglacial valley for a few miles above their junction, but the headwater portions of each stream are in new valleys.

There is, of course, a possibility that the depression in the region of East Troy drained eastward to the Lake Michigan basin. Wells indicate that a valley of considerable depth underlies the drift in the southern part of Milwaukee County. (See Pl. II, in pocket.) Its bottom at one point is as low as the level reached by the McKee well southwest of Troy Center. Rock is reached at numerous places in western Racine County and northeastern Walworth County at levels 100 to 300 feet higher. These points, concerning which the writer has information, are not too close together to exclude a buried channel of sufficient depth from having drained the Troy Basin eastward. Nevertheless, the writer is inclined to favor the interpretation shown on Plate II, which makes it tributary to Rock River. The reentrant in the Niagara margin in which the Troy Basin lies opens out broadly to the west and has much narrower digitate tributaries radiating northeastward and eastward. The well at Elkhorn shows that the Niagara dolomite does not extend west of that place. The well at the Yerkes Observatory shows the absence of the Niagara dolomite and of almost the entire Maquoketa shale, so that it seems highly probable that extensive erosion would have taken place along the shale belt west of Elkhorn. This is confirmed by the Bradley well at Delavan.

Wells in the area surrounding Lake Geneva show that the lake lies in a preglacial valley whose bottom is less than 640 feet above the sea or 220 feet below the present lake surface and 80 feet beneath the bottom of the lake at its deepest place. There is a possibility that this valley originally drained to the Lake Michigan Basin through southern Kenosha County. The writer has insufficient data to determine whether such an easterly course is probable, but he is inclined to think that it discharged westward, particularly if it is surely determined that the mapping of Troy Valley is correct.

NIAGARA ESCARPMENT.

The most prominent feature of the preglacial topography of the eastern part of the area was the Niagara escarpment. From the vicinity of Eagle at the north side of the reentrant in which lies the Troy Basin this escarpment extended first northward and then northeastward through Waukesha County as the east side of the Rock River valley. It is not known how abrupt was the slope in this part, but it probably had a maximum height of about 400 feet. Of this the upper part was composed of the Niagara dolomite. The slope on the shale below may have been less abrupt than on the dolomite. On the north side of the valley, in southwestern Washington County, the escarpment is so deeply covered with drift that even its location can be conjectured only from the logs of wells. It probably extended through the towns of Erin and Hartford (Tps. 9–10 N., R. 18 E.) in a broad curved reentrant that did not include some elevated dolomite-capped tracts that were separated by eroded depressions. One of these in secs. 6 and 7, T. 9 N., R. 17 E. (Ashippun Township), still presents a bold dolomite bluff facing westward, but in most places the rock slope is buried beneath a heavy deposit of glacial drift molded into drumlin forms. From Hartford the margin of the dolomite extended northwestward into the western part of the town of Herman, where it lies deeply buried beneath the drift about a mile east of the village of Iron Ridge. Wells show thicknesses of 200 feet or more of drift piled in great hills just west of the margin of the dolomite. From a narrow reentrant angle the Niagara margin swings out to the great ledge which extends from a mile north of Iron Ridge to 2 miles south of Mayville. The present bluff is about 200 feet in height. Were the drift removed from the lower land to the west the relief would be somewhat increased though probably not greatly, as Maquoketa shale is encountered at moderate depths in numerous wells. This may extend nearly or quite across the interval to the dolomite-capped elevation in the southern part of the town of Williamstown. Along the northwest side of this a bold bluff of dolomite overlooks the Horicon basin. In this part the preglacial relief of this outlier was probably 300 to 400 feet. Mayville is in the mouth of what was a deep reentrant in the mural escarpment, and its city well is reported[1] as having encountered the Galena dolomite beneath 198 feet of drift, or about 725 feet above sea level. Herman Christian's well, 2½

[1] F. T. Thwaites, who furnished this record, says it is probably inaccurate. Since writing the above, Mr. Thwaites has furnished a copy of the log of a well drilled in 1915 by F. M. Gray at the coke plant of the Northwestern Iron Co. at Mayville. This well reached bedrock 232 feet below the surface or about 700 feet above sea level.

miles farther east, in sec. 29, T. 12 N., R. 17 E. (Theresa Township), was said by the owner to have entered the dolomite at a depth of 217 feet, or 750 feet above sea level. Another well in sec. 18 of the same township did not reach rock at a depth of 212 feet, so that there is evidence of a considerable valley cut back in the margin of the Niagara upland. A continuation of the trough, extending from the vicinity of Theresa southeastward for 8 to 9 miles toward Schleisingerville, is now the site of a good-sized valley with a broad marshy bottom, drained northwestward to Theresa and thence through the broad reentrant to the Horicon Marsh west of Mayville. Whether the original direction of outflow was toward Mayville as now, or whether it drained southeastward to the valley described above as possibly extending northeastward from the Oconomowoc region, is not known. There is some evidence that the depth of the valley in the vicinity of the village of Theresa was less than it is either to the southeast or to the west. There is also doubt as to the direction which the waters took after leaving the reentrant at Mayville; they may have gone south to Rock River as now or north to Green Bay. The probabilities are that they went to Green Bay, although no borings between Mayville and Fond du Lac Township are known to reach so low a level as that reported for the bed-rock at Mayville. The 700-foot contour has therefore not been drawn in this part of the map.

The bold bluff which extends northward through the town of Leroy and, in southeastern Oakfield Township, swings around to the east, had originally a relief at least 100 feet greater than it has now. It thus formed an escarpment 300 to 400 feet in height, above which was a gently undulating upland. From its foot a similar moderately undulating plain rose gradually to the west. The offset in the escarpment continued, as now, eastward across the town of Byron to Eden Township, where a valley connected with the apex of the reentrant. From this locality the escarpment extended northward on the east side of the Winnebago Basin.

WINNEBAGO BASIN.

The difference in contour between the nearly flat plain south of Lake Winnebago, on which the city of Fond du Lac now stands, and the topography which would be revealed if the glacial and lacustrine deposits were removed is a matter of considerable interest. At Moore's old quarry, in the third ward, dolomite is exposed at the surface at an elevation of about 760 feet above sea level. Wells west of the city penetrate 40 to 70 feet of drift over dolomite. The records of the following wells show the thicknesses of the drift and lacustrine filling and the elevation of the rock at several points in, south, and east of the city, together with some at the north end of the lake outside the area shown on Plate II:

Thicknesses of drift penetrated by wells near Lake Winnebago.

South of Lake Winnebago.

Location.				Owner.	Thickness of drift penetrated.	Approximate elevation of rock above sea level.	Authority.
	T. N.	R. E.	Sec.		Feet.	Feet.	
Fond du Lac, fourth ward				City	106	650	Data in files of Wisconsin Geol. and Nat. Hist. Survey, by W. G. Kirchoffer after examination of samples at office of waterworks, Fond du Lac.
Fond du Lac Township	15	17	13, NE. ¼	Jacob Merton	255	645	Owner.
Do	15	17	21, SW. ¼	County Insane Hospital.	125	672	William Sealey, driller, Fond du Lac.
Do	15	17	22, SE. ¼	G. N. Mihill	95	695	Do.
Do	15	17	22, SE. ¼	Sanders Brewery	640	640	Owner.
Do	15	17	24, NW. ¼	S. B. Stanchfield	*a* 120		William Sealey, driller, Fond du Lac.
Do	15	17	25, NW. ¼	James Wright	114	745	Owner.
Do	15	17		Chas. Olem	181	(?)	P. Roughen, driller, Fond du Lac.
Do	15	17	32, NW. ¼	S. and P. Smith	100	740	Owner.
Do	15	17	35, NE. ¼	Michael Ryan	*a* 220	670	
Do	15	17	35, SE. ¼	A. F. Olmstead	200	665	Owner.
Fond du Lac or Byron Township				Emil Thrum	170	(?)	P Roughen, driller, Fond du Lac.
Byron Township	14	17	1, NW. ¼	Jas. Corcoran	120	760	Owner.
Do	14	17	2, NE. ¼	S. Miller	100	800	Do.
Do	14	17	3, NE. ¼	Mrs. Whittaker	80	810	William Sealey, driller, Fond du Lac.
Do	14	17	5, NE. ¼	A. D. Searl	*a* 105		
Eden Township	14	18	6, NW. ¼	?	*a* 90		
Do	14	18	6, SW. ¼	?	*a* 100		
Empire Township	15	18	19, NE. ¼	J. E. McCormick	150	688	J. E. McCormick.
Do	15	18	19, NE. ½	Rienzi Cemetery	150	795	Do.

a Wells do not reach rock.

Thicknesses of drift penetrated by wells near Lake Winnebago—Continued.

North of Lake Winnebago.

Location.	T. N.	R. E.	Sec.	Owner.	Thickness of drift penetrated.	Approximate elevation of rock above sea level.	Authority.
					Feet.	Feet.	
Harrison Township	20	18	4, NE. ¼	Saloon	90	685	George Schwalbach, driller, Harrison Township.
Do	20	18	4, SE. ¼	P. Kurey	100	720	Do.?
Do	20	18	8, SW. ¼	John Boertlein	97	703	Owner.
Do	20	18	9, NW. ¼	Wm. Borsche	100	720	George Schwalbach, driller, Harrison Township.
Do	20	18	9, NE. ¼	Mr. Stottler	140	675	Do.
Do	20	18	10, SW. ¼	G. A. Schwalbach.	140	670	Do.
Do	20	18	11, NE. ¼	Jno. Fischer	200	600	Do.
Do	20	18	12, SW. ¼	Jas. Pawelzock	200	600	Do.?
Do	20	18	13, SE. ¼	Heinrich Schafer	185	610	Do.?
Do	20	18	15, SE. ¼	?	100	695	
Do	20	18	16, NW. ¼	?	110	670	
Do	20	18	25, SW. ¼	John Wauda	275	500	Owner.
Do	20	18	36, NW. ¼	?	185	575	Gerhart Heupt, driller, Sherwood.
Do	20	19	5, NW. ¼	S. Thon	128	600	Owner.
Do	20	19	7, SW. ¼	H. Heupt	184	600	Gerhart Heupt, driller, Sherwood.
Do	20	19	8, SW. ¼	F. Dino	148	615	F. Dino, Harrison Township.
	20	19	8, NE. ¼	Wm. Dino	163	600	Do.
Do	20	19	17, SW. ¼	Jas. Schydzick	180	620	
Do	20	19	20, SW. ¼	Bernhard Kielgas.	100	720	Owner.

From the above data it appears that there is beneath Lake Winnebago and extending thence beneath the adjacent area to the south and north a buried channel or valley whose bottom is at least 150 feet below the present lake level. The depth to which John Wauda's well, one-half mile northwest of Clifton, in sec. 25, T. 20 N., R. 18 E. (Harrison Township), penetrated before entering the limestone indicates that the bottom of the depression at that place lies nearly 250 feet below the lake level. The writer, however, was unable to learn of any other wells north of the lake that showed drift at so low a level, so that it is not certain that this represents the original depth of the valley. East of this depression the bold escarpment rises to an upland which has a general elevation of about 1,000 feet above the sea and on which drift hills stand. In preglacial times there was thus a relief of 400 to 500 feet along this bluff. West of the lake the Galena dolomite and Trenton limestone rise to the surface somewhat above the level of the lake in the vicinity of Oshkosh and Neenah and Menasha. Most of the wells within a few miles of the west shore of the lake, concerning which information was obtained, enter rock at depths of 5 to 50 feet or so. From the records of a number of wells furnished the writer by George Muttart, driller (see p. 111), it is known that a buried valley 100 feet in depth, whose bottom is about 665 feet above sea level, underlies the city of Oshkosh. The stream in this valley must have joined that in the deep valley underlying the eastern part of the lake bed and have discharged thence northward to the Fox River valley somewhere east of the site of Kaukana. The present outlet of Lake Winnebago is from the west side of the north end of the lake, where the water escapes over the rock rim of the basin at Neenah and Menasha at an elevation of about 745 feet above sea level and flows thence in a channel cut down to or into the limestone much of the distance to Kaukana.

LAKE MICHIGAN DRAINAGE BASIN.

The crest of the Niagara dolomite escarpment north of the Oconomowoc region ranges from 1,000 to 1,100 feet above sea level in its higher parts. From the south side of the Oconomowoc reentrant southward to the Troy basin the higher parts of the top of the dolomite are 900 to 1,000 feet above sea level. Between the Troy basin and Lake Geneva and south of the Geneva valley the elevation, so far as known to the writer, is 800 to 900 feet above sea level. From this summit the surface of the dolomite declines eastward to a general elevation of about 500 feet near the line of the present lake shore. The variation known along this line is from 380 to nearly 600 feet above sea level. Information has been collected concerning hundreds of wells scattered over this lake-border part of the area, together with the locations and elevations of many exposures of the rock, yet the data at hand are insufficient to determine more than the largest features of the rock contours. So far as has been determined this dolomite slope was not greatly dissected, probably not so much so as in the areas to the west already discussed. No large buried valleys except those which notch the Niagara escarpment have been located, and, as described above, the relations seem to the writer to indicate that these valleys cutting the escarpment discharged either to tributaries of Rock River or to Green Bay. No very large valleys are known in eastern Wisconsin to have been tributary to the ancestral river valley supposed to have occupied the position of Lake Michigan basin prior to the earliest advance of the ice.

In describing the relations of Elkhart Lake and Sheboygan Swamp in the northwestern part of Sheboygan County (p. 46) it was indicated that these basins probably occupied part of a preglacial valley discharging to the Michigan basin south of Sheboygan. Mr. Laun informed the writer that in drilling a well at Lakeside Park on the west shore of Elkhart Lake unconsolidated material was penetrated to a depth of 240 feet without reaching rock bottom. About 1½ miles northwest of this point the river draining the swamp flows over the buried rock rim of the basin. There is some indication of short buried valleys farther south. In the vicinity of Milwaukee the elevation of the rock surface varies from about 100 feet above the lake level to 200 feet or more below that level—that is, from about 680 to 390 feet above sea level. There is, however, no evidence that the valleys head far westward. They seem rather to be but minor reentrants in the rock slope. A valley of considerable depth (see p. 124) probably underlies the drift in the southern part of Milwaukee County and may have been an eastward outlet to the Troy Basin. No important buried valleys are known south of this.

The configuration and elevation prior to the advent of the glaciers of the part of the area now submerged beneath the waters of Lake Michigan is entirely a matter of conjecture. The lake has a width of 50 to 80 miles. Opposite Milwaukee and Ozaukee counties, as shown by the Lake Survey charts, the bed of the lake lies 200 to 350 feet above the level of the sea. South of this the lake deepens in the middle of the basin until, opposite Racine, its bed lies approximately at sea level. This is the deepest part of the south half of the lake basin. Thence southward the bottom gradually rises to the head of the lake. From the relatively higher tract between Milwaukee and Muskegon, where the minimum depth of water in the middle of the basin is about 230 feet, the bed declines northward until, opposite the northern part of Manitowoc County, it lies more than 250 feet below sea level. The maximum depth of water in this part of the basin is about 145 fathoms or 870 feet. The north half of the basin continues deep until it reaches the vicinity of the Manitou, Fox, and Beaver islands and neighboring shoals. There is no through channel to the outlet, whose bottom is less than 500 feet above the sea. The maximum through depth of water, which is in the vicinity of the Lansing shoals, is not more than 60 feet. A. C. Lane[1] has published a map of the geologic formations and contours of rock surface of the southern peninsula of Michigan which shows a buried valley whose bottom is less than 300 feet above sea level extending across Emmet and Sheboygan counties just south of the Straits of Mackinac, from Little Traverse Bay, beneath Burt and Mullet lakes, to the basin of Lake Huron. It is not certain, however, that this is the position of a preglacial outlet channel.

A great buried valley is also shown extending in a broad curve from the head of Saginaw Bay to the vicinity of Manistee and Ludington, opposite Manitowoc County, Wis. On the Lake Michigan side the bottom of this valley lies below sea level, buried beneath 600 feet or more of drift, as shown by wells at Manistee and Ludington.[2] This valley is shown as shallowing toward Saginaw Bay to 400 feet above sea level, so that there does not appear to have been at this place an outlet deep enough to have drained the depths of the Lake Michigan basin, unless it be that the bottom of the valley has been subsequently raised by differential elevation toward the northeast. A certain amount of elevation of the region, including the north end of the Lake Michigan basin and the Straits of Mackinac is known to have taken place since the melting of the glaciers, as shown by the tilting of the ancient Lake Algonquin beach. This amounts to about 100 feet[3] in the vicinity of Harbor Springs, Emmet County, Mich., but even this amount added to the depth of the buried valley in Emmet and Sheboygan counties, Mich., would not make this channel sufficiently deep to drain the present depths of Lake Michigan. No other buried channel of greater depth is known to exist. The inference

[1] U. S. Geol. Survey Water-Supply Papers 182 and 183, p. 8, pl. 2, 1906-7.

[2] Lane, A. C., Michigan Geol. Survey, vol. 5, pls. 27-32, 1895.

[3] Goldthwait, J. W., Isobases of Algonquin and Iroquois beaches and their significance: Geol. Soc. America Bull., vol. 21, p. 232, 1910.

is, therefore, that the basin of Lake Michigan is now deeper than it was prior to the advent of the glaciers. It is not known how far below the bed of the lake the bedrock bottom of the depression lies. There probably is a certain amount of glacial drift and lacustrine deposits overlying the rock but, generally speaking, it seems probable that the part of the bottom of the basin along and west of the line of deepest water was a locus of more drift derivation than drift deposition.

East of this line within the basin and particularly in that part of western Michigan north of Muskegon drift accumulated in great thicknesses.

In a description of the geologic work in Wisconsin between the Devonian and glacial periods Chamberlin[1] discussed the question whether the Lake Michigan basin was due primarily to preglacial stream erosion or was principally excavated by the glaciers themselves. From a comparison of the conditions of stream erosion in the Mississippi Valley on the west side of the Wisconsin arch with the depth and configuration of the Lake Michigan basin and the bordering eastern part of Wisconsin, he concluded as follows: [2]

In short, all the evidence which we can gather seems to support the simple rational view, free from violent hypotheses, that erosion on the east and west sides of our State in preglacial times went forward in like manner and with like results, giving rise on the one hand to the Mississippi Valley and on the other to a similar valley occupying the site of Lake Michigan.

While, therefore, it is maintained that a valley of very considerable dimensions occupied the lake basin, it is not believed that it had the breadth and general depth and symmetrical contour which the lake now presents.

E. W. Claypole, in a paper on the preglacial geography of the region of the Great Lakes, refers to a possible buried southward outlet from the Lake Michigan basin, but presents no very convincing evidence of it.[3]

In a paper on the preglacial valleys of the Mississippi and its tributaries Leverett[4] makes the following statements concerning possible southward drainage from the Michigan basin in preglacial time:

The headwater portion of the streams forming the preglacial Wabash may prove to have been in the Lake Michigan basin. But if so the connection with the Wabash is through a very much narrower trough than that occupied by Lake Michigan. Borings at North Judson, Winamac, and Monticello, Ind., situated near the line connecting the head of Lake Michigan with the preglacial valley of La Fayette, go to a level about 100 feet below the surface of Lake Michigan before entering rock. But within a few miles east of this line, rock ledges have an altitude as great as the surface of Lake Michigan, while immediately west of this line they rise 90 to 125 feet above that level. This trough can not have in the vicinity of Monticello a breadth of more than 10 miles. Monticello is situated near the middle of the trough. The probabilities are, therefore, against the existence of a much deeper channel in it.

Borings have been made at frequent intervals westward and northwestward from this trough across northwestern Indiana and northeastern Illinois, and none of them show so low a rock surface as this line presents. They usually enter rock above the level of Lake Michigan. There seems, therefore, no ground for suggesting a southward or southwestward outlet of the Lake Michigan basin further west than the line which leads from the head of the lake to La Fayette, Ind. Furthermore, this seems the most probable line for a channel, since it follows nearly the western edge of the soft Devonian shales, where degradation would naturally proceed more rapidly than in the firm and resistant limestone ledges to the west.

If the Niagara dolomite continues plunging down eastward beneath the lake at the same rate of dip as between Waukesha and Milwaukee the base of the formation beneath the middle of the basin is about 1,100 feet below sea level and unless the dolomite is much thicker than in eastern Wisconsin its surface lies well below the deepest parts of the basin. That the dip of the formation does not decrease appears from the fact that a well at Muskegon, Mich.,[5] on the east shore of the lake nearly opposite Milwaukee did not reach the Niagara dolomite at a depth of 2,600 feet, or about 2,000 feet below sea level. This well penetrated shale, principally, to a depth of 1,700 feet, or about 1,100 feet below sea level. Below this level the well was drilled through 900 feet of strata, regarded as of Hamilton, Oriskany, Helderberg, and Salina age, principally limestone and dolomite. Wells at Allegan, Ludington, and Manistee, Mich.,[6] penetrate drift to depths ranging from 240 to 640 feet, and beneath this principally shale to depths ranging from 960 to 1,595 feet—that is, to levels ranging from 300 to 1,000 feet below sea level. From this it is seen that the lake basin is probably for the most part excavated in easily erodable shales, material which would favor the remodeling of a river valley with branching tributaries into a broader and deeper basin of smoothly rounded contours as the result of its being traversed longitudinally by one of the lobes or by a succession of lobes of the continental ice sheet.

[1] Chamberlin, T. C., Geology of Wisconsin, vol. 1, pp. 253-259, 1883.
[2] Idem, p. 257.
[3] Canadian Naturalist, vol. 8, new ser., pp. 187-206, 1878.
[4] Leverett, Frank, The preglacial valleys of the Mississippi and its tributaries: Jour. Geology, vol. 3, pp. 744-745, 1895.
[5] Lane, A. C., Michigan Geol. Survey, vol. 5, pl. 43, 1895.
[6] Idem, pls. 4, 27-32.

CHAPTER V.—OUTLINE OF PLEISTOCENE HISTORY.

GLACIAL STAGES.

DRIFT SHEETS AND INTERVALS.

The long interval following the emergence of the borders of Wisconsin from the waters of the Devonian seas was brought to a close by a change in climatic conditions that resulted in the development of vast sheets of ice that covered the northern part of the North American Continent as the great ice cap now covers Greenland. (See fig. 6.) There were three great centers of accumulation; one on the Lab-

FIGURE 6.—Map of North America showing the area covered by the Pleistocene ice sheets at their maximum extension and the main centers of accumulation.

rador Peninsula, one on the Keewatin Plateau west of Hudson Bay, and one, the Cordilleran, in the mountain region of western Canada. From these centers the ice spread radially, that from the Labrador and Keewatin centers coalescing and extending southward into the area of the United States. The period of glaciation was marked not by a single advance and melting of the ice but by successive stages of glaciation during which the ice accumulated and spread widely over the surface of the land, alternating with stages during which the climate became so much warmer that the ice in large part melted and the glacial margins retreated northward. Whether or not the ice wholly disappeared during these intervals of deglaciation is not known, but the presence of buried soils, vegetal matter, and faunal remains at several horizons indicates that the climatic conditions, during the interglacial stages, simulated those of the present. Evidences of more than one stage of glaciation and deglaciation are found in southeastern Wisconsin, but it has not been determined that this area was invaded by ice at each stage of continental glaciation.

The following outline of stages of glaciation and intervals of deglaciation is in part general for the northern portion of the United States lying east of the Rocky Mountain region and in part it refers specifically to southeastern Wisconsin and northern Illinois.

Outline of stages of glaciation and deglaciation in order of age, the oldest at the top.

Pleistocene.

Pre-Kansan stage of glaciation (of Chamberlin). (Possibly represented in southeastern Wisconsin.)
Aftonian stage of deglaciation (of Chamberlin). (Not certainly known to be represented in southeastern Wisconsin.)
Kansan stage of glaciation (of Iowa geologists). (Possibly represented in southeastern Wisconsin.)
Yarmouth stage of deglaciation (of Leverett). (Possibly represented in southeastern Wisconsin.)
Illinoian stage of glaciation (of Leverett). (Abundant evidence of presence of drift of this stage in southeastern Wisconsin.)

Sangamon stage of deglaciation (of Leverett). Main stage of loess deposition. Regarded as closely associated with the closing phase of the Iowan stage of glaciation (of Iowa geologists), and the early part of the succeeding Peorian stage of deglaciation. Peorian stage of weathering and soil formation (of Leverett).	In southern Wisconsin and northern Illinois represented by the superficial modification of the Illinoian drift by weathering and erosion, by the deposition of the overlying loess and loamy clay, by the formation of alluvial and lacustrine deposits, and by the growth and accumulation of vegetal material.

Wisconsin stage of glaciation (of Chamberlin):
- Early Wisconsin drift in Illinois:
  - Substage 1. Shelbyville and Champaign morainic systems.
  - Substage 2. Bloomington and Marseilles morainic systems. (With the Bloomington system is probably to be correlated the Marengo ridge of western McHenry County, Ill., and the Brooklyn moraine in southern Wisconsin.)
- Later Wisconsin drift, as represented in southeastern Wisconsin, Illinois, northwestern Indiana, and southwestern Michigan:
  - Substage 3:
    - a. Great bowlder belts and accompanying moraines, including, perhaps, the Minooka moraine of Illinois.
    - b. Kalamazoo morainic system of Lake Michigan glacier in southern Michigan and northern Indiana.

	Delavan lobe of Lake Michigan Glacier.	Green Bay Glacier.
c. Valparaiso morainic system of Lake Michigan Glacier. (As mapped in northwestern Indiana, northeastern Illinois, and southeastern Wisconsin it may include undifferentiated deposits of the Kalamazoo morainic system.)	Genoa moraine. Darien moraine.	Johnstown moraine.
	Elkhorn moraine........	Milton moraine.
	Other morainal deposits.	Lake Mills morainic system and other morainal deposits.
d. Lake Border morainic system of Lake Michigan Glacier........................		Green Lake moraine. Waupun moraine. Rush Lake moraine. St. Anna moraine.

	Lake Chicago.	Michigan.
Substage 4: Readvance and deposition of red till by Lake Michigan and Green Bay glaciers in eastern Wisconsin. Lake Chicago submergence.[1]	Glenwood stage. Calumet stage. Low water stage. Toleston stage.	Port Huron morainic system.

Glacial Lake Algonquin.
Nipissing Great Lakes.

Recent.

Lake Michigan.

[1] Only those stages of the Great Lakes involving Lake Michigan basin are included in this outline.

PRE-KANSAN STAGE OF GLACIATION.

Deposits of glacial drift found in southern Iowa show that at the earliest known stage of glaciation, the pre-Kansan or sub-Aftonian (of Chamberlin), the ice from the Keewatin center extended as far as southern Iowa.[1] The limit of Labradorean ice in the Mississippi Valley at this stage is not known. Certain deposits bordering the northern part of the Driftless Area in Wisconsin and regarded by Weidman as pre-Kansan glacial drift may be evidence of glaciation in Wisconsin at this early stage. The ice may have extended over eastern Wisconsin and southward into Illinois. It has been suggested by Weidman that certain scattered drift deposits along the eastern border of the Driftless Area in Wisconsin may be the residuum left after long erosion of such an early drift sheet. (See p. 170.) However, there are grounds for referring this scattered drift to a later stage.

AFTONIAN INTERGLACIAL STAGE.

Very interesting soil and vegetal deposits and faunal remains of the Aftonian interglacial stage have been found in Iowa, but none are certainly known to represent this horizon in the area under discussion.

KANSAN STAGE OF GLACIATION.

At the Kansan stage of glaciation the Keewatin ice sheet reached its southernmost limit in northeastern Kansas and northern Missouri. The thickness of the drift in parts of Rock and Walworth counties, Wis., east of Rock River (with certain other phenomena) indicates that it may include buried drift referable to a stage earlier than that of the surficial drift and possibly referable to the Kansan stage of glaciation.

To deposition at one of these early stages of glaciation (Kansan or pre-Kansan) may also be referred the conglomerate exposed at intervals along the east side of the Rock River valley south of the State line.

YARMOUTH INTERGLACIAL STAGE.

The only known deposits in southeastern Wisconsin that may possibly be referred to the Yarmouth interval of deglaciation have been found beneath the Illinoian drift in well drillings. Their correlation, however, is wholly problematic.

ILLINOIAN STAGE OF GLACIATION.

There is abundant evidence of the extension of the Labrador ice sheet into eastern Wisconsin at the Illinoian stage of glaciation, although the relations of the Keewatin Glacier in the area west of Mississippi River are not yet clearly understood. North of the southern tier of Wisconsin counties the deposits of this stage are obscured by those of a later glaciation. Outside the limits of this later drift, however, in Walworth, Rock, and Green counties, the Illinoian glacial deposits are well developed, extending westward to the Driftless Area and southward over much of Illinois. The composition of the drift and the trend of glacial striæ in southern Wisconsin and northern Illinois show that at this stage the glacial movement was westerly across the Rock and Sugar river valleys, shifting to northwesterly as the ice closed about the southeastern side of the Driftless Area. That the unglaciated area was not overwhelmed at this stage of glaciation was due not to its greater elevation but to the fact that the main axial movement of the ice was directed farther south by the great trough in which now lies Lake Michigan.

SANGAMON INTERGLACIAL STAGE.

The melting of the Illinoian ice sheet was followed by a considerable interval of deglaciation, during which the surficial parts of the Illinoian drift were subjected to modification by weathering, a soil (the Sangamon) was developed, and the surficial configuration of the drift was modified by stream erosion. During the recession of the margin of the Illinoian ice sheet in northern Illinois the marginal waters discharged southwestward to Mississippi River across a series of cols and intervening valleys, thus reestablishing Rock River below Rockford, Ill., along a new course.

MAIN STAGE OF LOESS DEPOSITION.

The development of the glacial deposits in northeastern Iowa has led to the belief that after the extension of the Labrador ice at the Illinoian stage over so large a part of Illinois and adjacent areas and after a succeeding interval of deglaciation, to which the name Sangamon stage was given, there occurred an exten-

[1] Credit for data used in this outline other than the writer's is given in the detailed discussion (Chapters VI-XI).

sion of the Keewatin ice southward into northeastern Iowa. For this latter stage of glaciation the name Iowan has been used. Certain characteristics of the drift in northern Illinois and in Rock and Walworth counties, Wis., also led to the view that at the same stage the Labrador Glacier extended across this latter area southwestward to Mississippi River. Later studies, however, have led to the abandonment of belief in an Iowan invasion of the ice into this part of the region east of the Mississippi.

Following the Sangamon stage came a time during which large quantities of dust or loess were blown about by the wind and spread widely over the weathered and eroded surface of the Illinoian and older drift deposits and also over unglaciated parts of the Mississippi Valley. It is supposed that this loess deposition was closely associated with the closing phase of the fourth (Iowan) pre-Wisconsin stage of glaciation and the early part of the succeeding Peorian stage of deglaciation.

PEORIAN STAGE OF WEATHERING AND SOIL FORMATION.

In the region of Peoria, Ill., the post-Sangamon loess shows evidence of having been exposed to leaching and oxidation for a time before the deposition of the Wisconsin glacial drift which there overlies it.

WISCONSIN STAGE OF GLACIATION.

EARLY WISCONSIN SUBSTAGES.

Generally speaking, the continental glaciers at the Wisconsin stage fell somewhat short (in Iowa and Illinois more than 100 miles short) of reaching the southern limit of glaciation. In places in Wisconsin the Labrador ice encroached on the eastern margin of the Driftless Area and in eastern Ohio it reached the unglaciated area. In the Rocky Mountain region the Keewatin ice sheet probably reached the maximum limit of continental glaciation. Being the last main stage of glaciation many of the distinctive phenomena resulting from the occupancy and melting of the ice are well preserved and permit of much greater detail of interpretation than is possible in connection with the earlier glacial stages.

From the study and mapping of the various phenomena, particularly the terminal moraines, it has been determined that the Wisconsin stage of glaciation was rather complex. Following the maximum extension of the glaciers there was a series of successively less extensive developments of the ice alternating with more or less extensive recessions of the ice fronts as the result of melting of the glaciers. This is illustrated in Plate XX (p. 194), a map prepared by Leverett and Taylor,[1] on which are shown the more important positions of the fronts of the lobes of the Labrador Glacier as indicated by terminal moraines. In the early part of the Wisconsin stage the ice in Illinois extended to a position marked by the Shelbyville morainic system. (See Pl. XXIII, p. 208.) Following this it receded successively to the positions of the Champaign, Bloomington, and Marseilles morainic systems.

LATER WISCONSIN SUBSTAGES.

ADVANCE OF THE ICE.

A somewhat more marked interval of recession of the glacial margins appears to have been followed by a somewhat greater differentiation of glacial lobes and some shifting of the lines of axial flow as the ice again deployed over the surface of the land. This advance has usually been designated the late Wisconsin substage. The limit of readvance of the Lake Michigan Glacier in Illinois and Indiana at this time is marked by the Valparaiso and Kalamazoo morainic systems. In eastern Wisconsin the differentiation and deployment of a great lobe of the ice sheet, known as the Green Bay Glacier, resulted from the controlling influence of the broad Green Bay–Lake Winnebago trough and of the Niagara escarpment on the east. On the west this glacier encroached somewhat on the great Driftless Area, which had escaped glaciation at the earlier stages of ice advance. The limit of the advance is marked by the Johnstown moraine which extends southward in a broad curve through Adams and Sauk counties and into Dane County, past the cities of Kilbourn and Baraboo and over the Baraboo quartzite bluffs and the valley of Wisconsin River. At a point southwest of Madison the moraine, curving southeastward, enters the area of the Illinoian drift. Entering Rock County the curving moraine swings eastward, crosses the Rock

[1] Leverett, Frank, and Taylor, F. B, The Pleistocene of Indiana and Michigan and the history of the Great Lakes: U. S. Geol. Survey Mon. 53, pl. 5, 1915.

River valley north of Janesville and coalesces with the moraines of the Lake Michigan Glacier in northwestern Walworth County.

Topographic conditions and the convergence of the ice currents of the Green Bay and Lake Michigan glaciers led to the extension from the Lake Michigan Glacier of a minor lobe (the Delavan lobe), whose outer limits are defined by the Darien and Genoa moraines. These moraines curve eastward across Walworth County past Lakes Geneva and Delavan in an arc of nearly 180° and, in western Racine and Kenosha counties, merge with the Valparaiso morainic system, which is traced southward through northeastern Illinois and northwestern Indiana about the head of the Lake Michigan basin. (See Pl. XXIII, p. 210.) In southern Michigan and northern Indiana the Kalamazoo morainic system is developed next outside the Valparaiso system and appears to mark the outer limit of the ice advance on the east side of the Lake Michigan lobe. With these are correlated, respectively, the Kalamazoo morainic system and the Charlotte morainic system of the Saginaw lobe and the Mississinawa morainic system, and later moraines of Indiana and Ohio.

The distribution in southeastern Wisconsin of the several moraines and other phenomena of the Lake Michigan and Green Bay glaciers is shown in Plate III (in pocket), and an extended description and delineation of the geologic history is presented in Chapters VI to XI. The purpose of this chapter is to sum these up in the barest outline.

During the advance of the glaciers a till sheet of considerable thickness was added to the earlier drift within the area overrun. The conditions of advance and radial deployment of the ice currents, particularly those of the Green Bay Glacier, also furnished the conditions requisite to the building up and shaping of a remarkable series of elongated ridges and elliptical hills comprising a large number of variations of the drumlin type, whose distribution and axi-radial arrangement are well shown on the map. (See Pls. III and IV, in pocket.) Systems of glacial striæ, whose trends are shown by arrows on the map, were graven on the surface of the bedrock by the moving rock-shod ice. Streams of glacial waters flowing in channels or tunnels in the lower part of the ice and discharging at the ice front filled their courses with gravels, so that when the overarching ice and the frigid retaining walls melted away the gravels were left winding over the surface as sinuous ridges known as eskers. Waters discharging at the ice fronts were in places ponded in obstructed valleys or basins forming temporary lakes, such as glacial Lakes Wisconsin and Baraboo, which spread over the plain between and north of the Baraboo Bluffs and discharged across the divide in Jackson County to Black River. In these lakes were deposited fine laminated silts and near the ice front was spread an extensive outwash terrace of sand and gravel. Similar outwash material was swept down the valleys of Wisconsin, Sugar, and Rock rivers, adding to the terrace deposits and valley trains formed during the earlier stages of glaciation.

RECESSION OF THE ICE FRONT.

Deposition of recessional moraines.—When as the result of the amelioration of the climate the ice again began to melt, the retreat of the glacial margins did not proceed without interruption. A succession of minor marginal moraines within the outer moraine indicates stages of halt, or of readvance and halt, during which these marginal accumulations were formed. There is a general correspondence between such phenomena of the Green Bay and Lake Michigan glaciers, and correlation of the principal ones with moraines extending farther east into western Pennsylvania, New York, and Ontario shows that these successive deposits indicate glacial oscillations due to climatic variations of more than local extent.

Elkhorn and Milton moraines.—The first of these stages of recession of the Green Bay Glacier ended with the formation of the Milton moraine, which lies a few miles within the Johnstown moraine. To the east of this the Delavan lobe contracted to the Elkhorn moraine, while the main front of the Lake Michigan Glacier still stood at the Valparaiso morainic system. As the ice on the east of the Kettle interlobate moraine thinned and melted away in northern Walworth County, great quantities of outwash gravel were swept out from the Green Bay Glacier (which continued snugly pressed against the interlobate moraine), burying great masses of ice of the Delavan lobe. The basins of the Lauderdale and other small lakes in northern Walworth County resulted from the subsequent melting of these ice masses and the settling of the gravels. Lakes Delavan, Geneva, and Como also originated about this time.

Lake Mills morainic system.—The next halts of the front of the Green Bay Glacier were along the lines marked by the deposits grouped as the Lake Mills morainic system. These deposits (see pp. 277–284) are for the most part patchy, discontinuous, and topographically insignificant. They are not at all of the rank of the great bulky Johnstown and Elkhorn moraines or the Kettle interlobate moraine. The morainal system into which they are grouped (if indeed it be justifiable to treat such deposits as constituting a morainic system) is, therefore, probably the index of events correspondingly insignificant as compared with the major facts of the glacial history.

The recession of the front of the Green Bay Glacier to the Lake Mills morainic system cleared the Wisconsin Valley and permitted glacial Lakes Wisconsin and Baraboo to be drained about the east end of the Baraboo Bluffs. The reestablishment of the drainage lines in new courses across the drift located Wisconsin River across a broad buried sandstone ridge in the vicinity of Kilbourn; and the erosion of the new channel, a narrow gorge cut in the sandstone, gave rise to The Dells, the most famous and beautiful feature of the Wisconsin Valley. Baraboo River, instead of discharging to a stream flowing southward through the Lower Narrows and the Devils Lake Gorge, as in preglacial time, now flowed eastward through the Lower Narrows and joined the Wisconsin near Portage. The melting of the ice also cleared the basins of the four lakes of the Madison region and reestablished Rock River. The flooding of a large depression on the line of the ancient Rock River valley north of the moraines initiated Lake Koshkonong, and the outflow at the lowest outlets across the moraine reestablished Rock River in a new course. The melting of ice masses buried in the morainal and outwash terrace gravels in northwestern Waukesha County gave rise to the multitude of beautiful lakes which make the Oconomowoc region so famous as a summer resort.

On the east, when the front of the Lake Michigan Glacier receded to and beyond the easternmost of the several lines of deposits which mark the decadence of the Delavan lobe and which are connected with the Valparaiso morainic system, the basins of Pewaukee Lake and the basins of the small lakes in southeastern Waukesha County and western Racine and Kenosha counties were cleared of ice.

Green Lake and associated moraines.—The next stage in the deglaciation of the area is marked by a group of similar slight moraines of the Green Bay Glacier which are designated, in order from older to younger, the Green Lake, Waupun, Rush Lake, and St. Anna moraines. These are correlated with the ridges of the Lake Border morainic system of the Lake Michigan Glacier, which have been traced southward from Sheboygan County and through northeastern Illinois and northwestern Indiana, about the head of the Lake Michigan basin and thence northward into Michigan, and which have been generally correlated by Leverett with the Lansing moraine of the Saginaw lobe in Michigan and the Defiance moraine and associated moraines of the Huron-Erie lobe in Ohio. (See Pl. XXIII, p. 208.)

The recession of the ice front eastward across Marquette and Green Lake counties caused the ponding of waters in the Fox River valley and their overflow across the low divide near Portage to Wisconsin River. The flooding of the basins of Puckaway, Green, and Rush lakes resulted from the recession of the ice front from the morainal deposits which blocked the underlying preglacial valley and left the basins inclosed. Beaver Dam Lake and the smaller adjacent lakes were formed in like manner, and Horicon Lake spread over the basin now occupied by the big marsh north of the morainal dam on which the city of Horicon is built. All these recessional moraines merge with the great Kettle interlobate moraine, into connection with which on the east are traced several moraines of the Lake Border system. The St. Anna moraine is overlapped by later deposits and can not be correlated directly with any one of the Lake Border moraines.

Lake Duluth.—The next event of importance in the history of the glaciated area appears to have been a considerable recession of the lobate margin of the ice sheet, followed by a distinct readvance. This succession of events appears to be well marked all across the area from eastern Wisconsin to western New York and may involve the Lake Superior basin and districts to the west in Minnesota and the Dakotas. The contracting of the glacial margins in the Lake Superior basin caused the flooding of its western part up to the level of the col leading to the St. Croix Valley. This high-level glacial lake has been designated Lake Duluth. When the recession of the convergent margins of the Superior and Green Bay glaciers cleared a lower pass across the northern peninsula of Michigan, the pent-up waters found an outlet southward into the Green Bay-Lake Winnebago valley and thence eastward across Door Peninsula from the Green Bay valley to the Lake Michigan basin.

Lake Chicago (Glenwood beach).—In the meantime the contraction of the margins of the Lake Michigan Glacier had resulted in the flooding of the south end of the Lake Michigan basin and the initiation of glacial Lake Chicago. The waters of this lake found an outlet across the Valparaiso morainic system by the valley now traversed by Des Plaines River southwest of Chicago and thence to Illinois River. (See fig. 20, p. 327.) The highest well-marked beach of Lake Chicago is the Glenwood beach, which has an elevation of about 640 feet above the sea, or nearly 60 feet above Lake Michigan. This beach has been traced northward on the west side of the basin to the vicinity of Wind Point near Racine. From Milwaukee northward it is believed to be represented by a deposit of stratified sand and gravel exposed in the lake bluff overlying the bluish glacial till and underlying laminated red clay and red till.

READVANCE OF THE ICE.

Deposition of red till.—The occurrence of red clay in a belt bordering Lake Winnebago and Green Bay and the western part of the Lake Michigan basin as far south as Milwaukee is explained on the supposition that the southward-flowing waters from the Lake Superior basin brought with them a considerable quantity of fine red silt which was precipitated in quiet waters in the Green Bay-Lake Winnebago valley and in the western part of the Lake Chicago as far south as Racine.

Following the deposition of the red silt the ice in the Lake Huron basin readvanced to the main moraine of the Port Huron morainic system and the ice in the Lake Michigan basin and the Green Bay-Lake Winnebago valley readvanced into eastern Wisconsin. On the east side of the basin the Lake Michigan Glacier extended to a moraine which has been traced southward to the lake shore near Muskegon, Mich. (Pl. XXIII, p. 208) and the Glenwood waters of Lake Chicago were crowded southward as far as the latitude of Racine. On the Wisconsin side the ice reached the shore of glacial Lake Chicago at Milwaukee and extended upon the land approximately to the line of Milwaukee River.

The extent of this encroachment on eastern Wisconsin beyond the position of the present shore line gradually increased northward to about 15 miles in the latitude of Sheboygan and Plymouth, in Sheboygan County. The expanding glacier overrode the blue-gray Wisconsin till, the lacustrine sands, and the red silts in the western part of the basin; and much red clay was commingled with pebbles, carried inland and spread over the blue-gray drift as red till. Near Random Lake, in southern Sheboygan County, the margin of the red till overlaps a part of the Lake Border morainic system; farther north it encroaches on a drumlin topography; and in Manitowoc County it covers even the Kettle interlobate moraine.

The distribution of the red drift and the trend of glacial striæ in western Manitowoc County and Calumet County (Pl. XXXVI, p. 316) show that the front of a minor lobation of the glacial margin curved northwestward to the crest of the Niagara escarpment. In the Lake Winnebago basin a lobe extended southward nearly to the south line of Fond du Lac township and formed a well-marked red-drift moraine. The distribution of the red drift in the Fox River valley shows that the ice extended westward to the vicinity of Berlin. The lake which occupied the Winnebago basin during the readvance and the preceding recession of the ice front was thus nearly obliterated, and the waters were again ponded in Fox River valley southwest of Berlin.

Lake Chicago (later stages).—The Glenwood stage of glacial Lake Chicago was initiated (see p. 326) as the margin of the Lake Michigan Glacier receded from the Valparaiso morainic system. The waters appear to have continued at the Glenwood shore line during the recession of the ice front from the Lake Border moraines, while the red lacustrine silts were being deposited during the readvance of the ice to the main moraine of the Port Huron morainic system in Michigan and during the deposition of the red till in Wisconsin. The lake appears also to have been maintained at approximately the same level during the next stage of the glacial melting, when the ice again disappeared from the south half of the basin. The waters of the Glenwood stage thus encroached on the lower parts of the red drift area northward to a point midway between Sheboygan and Manitowoc. Similar extension northward from Muskegon on the east side of Lake Michigan is reported by Leverett and Taylor.

The next definite stage of the lake is marked by the Calumet beach, which has an elevation of about 35 feet above the present lake level, or 616 feet above the sea. The Chicago outlet had been gradually cut down, but the final drop to the Calumet level appears to have been rather sudden, as if due to the giving way of the last obstruction to the outflow. The Calumet beach is well marked northward to Wind Point north of Racine, but there is little trace of it farther north owing to its removal at later lake stages.

Evidence found in the depth of filling in the lower parts of valleys tributary to the lake and in peat buried beneath beach deposits of a later stage indicates that a low-water stage followed the Calumet stage. It appears that the opening of a lower outlet to the northeast drew down the water level something like 50 feet below the present level of Lake Michigan. Following this either a readvance of the ice or a northward elevation of the land closed this lower outlet and renewed the discharge through the Chicago outlet. Evidently there had been considerable erosion of the outlet during the Calumet stage, for the next definite shore line, leading into this outlet, the Toleston beach, is about 22 feet above Lake Michigan, or 603 feet above the sea. It is possible that the low-water stage may have followed rather than preceded the Toleston stage.

GLACIAL LAKE ALGONQUIN.

When the ice front had retreated so far as to permit the confluence of the waters of the Superior, Michigan, and Huron basins, a single great lake was formed, known as glacial Lake Algonquin. (See Pl. XXXVII, p. 336.) The outlet was eastward through the Trent Valley to the Ontario basin via Kirkfield, Ontario, and thence across the Ontario basin (occupied by glacial Lake Iroquois) to the Mohawk Valley and the Hudson. After a time, the Kirkfield outlet was closed by uplift of the land, and the waters for a time probably discharged partly by the Chicago outlet and partly past Port Huron, Mich., to Lake Erie, and thence to Lake Iroquois and Mohawk River.

Deepening of the Port Huron outlet gradually reduced the flow from the Chicago outlet, and continued recession of the glacial margins finally opened the Ottawa Valley and permitted discharge that way. This is believed to have drawn down the waters in the Lake Michigan basin to a level below that of the present lake in the southern half of the basin. This stage may be regarded as closing the Pleistocene history of the area under discussion, as it terminated the direct influence of the glaciers on the phenomena of the district.

POSTGLACIAL LAKES.

NIPISSING GREAT LAKES.

The discharge eastward from North Bay, Ontario, and thence to Ottawa River was finally terminated by elevation of the land and the southward tilting of the lake basins, in consequence of which the flow through Port Huron outlet was resumed. The three upper lakes at this stage are known as the Nipissing Great Lakes. (See Pl. XXXVIII, p. 338.) The Nipissing shore line in eastern Wisconsin is about 14 feet above the level of Lake Michigan and is well marked in places by a bluff and cut terrace. (See Pl. XXXIX, p. 340.) The northeastward elevation of the land which was initiated at the time of Lake Algonquin continued but did not affect the attitude of the shore lines in the southern half of the Lake Michigan basins. North of latitude 44°, however, the ancient shore line gradually rises northward, showing the effects of the differential elevation. The Nipissing beach, at the north end of the basin, is now nearly 50 feet higher than the present beach of Lake Michigan, and the Algonquin shore line stands about 250 feet above the lake.

LAKE MICHIGAN.

The adjustment of the depth and capacity of the outlet at Port Huron to the discharge from the upper lakes gradually lowered the water level in the Huron and Michigan basins to their present altitude and initiated the present stage of the lakes. To this stage of the waters in the western basin the name "Lake Michigan" is applied.

CHAPTER VI.—PRE-WISCONSIN GLACIAL DRIFT.

ILLINOIAN DRIFT AND EARLIER DEPOSITS.

GENERAL RELATIONS.

In southern Wisconsin and northern Illinois, outside of the well-marked terminal moraines formed at the Wisconsin stage of glaciation and their bordering gravel terraces, is a deposit of glacial drift which bears evidence of somewhat greater age. (See fig. 7, p. 153.) The greater part of this tract lies in Illinois, where it has been studied by Frank Leverett and previously, in part, by I. M. Buell and Oscar Hershey. Hershey has published several papers treating of Pleistocene deposits and associated phenomena observed in the region, and Buell[1] has discussed some of the phenomena in his paper on the bowlder trains from the outcrops of the Waterloo quartzite area.[1] The writer has also had access to a more extended unpublished manuscript by Buell on the same subject, from which he has obtained considerable information concerning the pre-Wisconsin drift of southern Wisconsin and northern Illinois. Leverett[2] has embodied with his own observations the results of earlier studies by others in Illinois.

More or less difference of opinion has existed concerning the number and ages of the glacial invasions of this tract (between the Wisconsin terminal moraines and the Driftless Area), and some change of opinion has taken place; so that it has been thought best to present herewith not only a somewhat detailed description of the deposits north of the State line, which have been studied in detail by the writer, but also to include the writer's interpretation of the phenomena in the northern Illinois district, based on a study of the earlier papers and on a somewhat careful personal examination of a belt 10 to 20 miles in width bordering Rock River on the east and west, from the State line to Morrison. As the earlier views have been stated somewhat fully by Leverett in his monograph, to which there is easy access, the present presentation is based principally on the writer's own observations. The description and interpretations have been submitted to both Chamberlin and Leverett in correspondence and conference and are believed to be in accordance with their present opinions.

The conclusion reached is that the uppermost drift exposed outside the Wisconsin moraines and terraces is of practically identical composition throughout the tracts in southern Wisconsin and in adjacent counties of northern Illinois and composes one and the same drift sheet; and that, though it shows differences in its degree of superficial alteration by weathering and erosion in different parts of the area, these differences, after taking into account original variations in the preglacial topography and in the thickness of the drift, are insufficient to warrant referring the deposits in different parts of the area to two or more different stages of glaciation separated by stages of deglaciation. There may be an underlying older drift sheet, but the main and uppermost deposits of glacial drift seems to have been deposited at the Illinoian stage of glaciation when the great ice sheet centering in Labrador spread over almost all of Illinois and encroached on eastern Iowa.

PRE-WISCONSIN DRIFT IN WISCONSIN.

SUBDIVISIONS OF THE AREA.

Different parts of the tract present somewhat different aspects, from which have arisen legitimate differences of opinion as to their interpretation. Because of this and for convenience of comparison these several parts are discussed in three more or less arbitrary subdivisions, the first lying between Rock River and the Darien moraine, in southeastern Rock County and southwestern Walworth County, Wis.; the second between Rock and Sugar

[1] Buell, I. M., Bowlder trains from the outcrops of the Waterloo quartzite area: Wisconsin Acad. Sci. Trans., vol. 10, pp. 485-509, 1895.
[2] The Illinois glacial lobe: U. S. Geol. Survey Mon. 38, 1899.

rivers; the third principally in Green County, Wis., and extending from Sugar River to the limits of glaciation on the west. Following this, corresponding tracts in the northern counties of Illinois are considered.

PRE-WISCONSIN DRIFT IN TRACT EAST OF ROCK RIVER.

CHARACTER.

The drift overlying the upland between the preglacial Troy Valley on the east and the Rock River valley on the west, in Rock and Walworth counties, Wis., is, in general, unmodified till of the ordinary bowlder clay type. Several cuts on the lines of the railroads afford excellent exposures of the upper 15 to 20 feet of the drift. Generally on fresh exposure the clayey matrix of the till has a pinkish tinge, only faintly perceptible on small pieces at close range but giving a decided pinkish or reddish tint to the section as a whole when viewed from a distance of a few yards. At some exposures the tint is so decided as to be noticeable at a much greater distance. In other sections the color is a light grayish-buff. At moderate depths the clay takes on a light-bluish cast, which in numerous wells is seen to persist through considerable thicknesses. There is usually a good deal of quartz sand mixed with the clay, and embedded in this finer material is the usual content of subangular and glaciated fragments of rock, ranging in size from coarse sand to bowlders 2 to 3 feet in diameter. By far the greater part of this stony material is in pebbles less than 10 inches in diameter, but some larger stones are usually present. In many places the drift contains layers and pockets of stratified gravel and sand, most of the wells penetrating more or less of this assorted material. Other wells penetrate considerable depths of solid clay before any sand or gravel is reached.

Where the carbonate of lime has not been removed by the leaching action of percolating waters since it was deposited, the clay matrix of the till is usually highly calcareous. Testing with acid showed the leaching to be thorough for 2 to 5 feet from the surface, usually from 2 to 4 feet. Most of the limestone pebbles have been removed from the upper part of this zone, and those just below are roughly etched by solution or are rotten. A cut near the crest of a drumlin in western Walworth County showed the following section:

Exposure of till in the NW. ¼ sec. 34, T. 2 N., R. 14 E. (Bradford Township), Wisconsin.

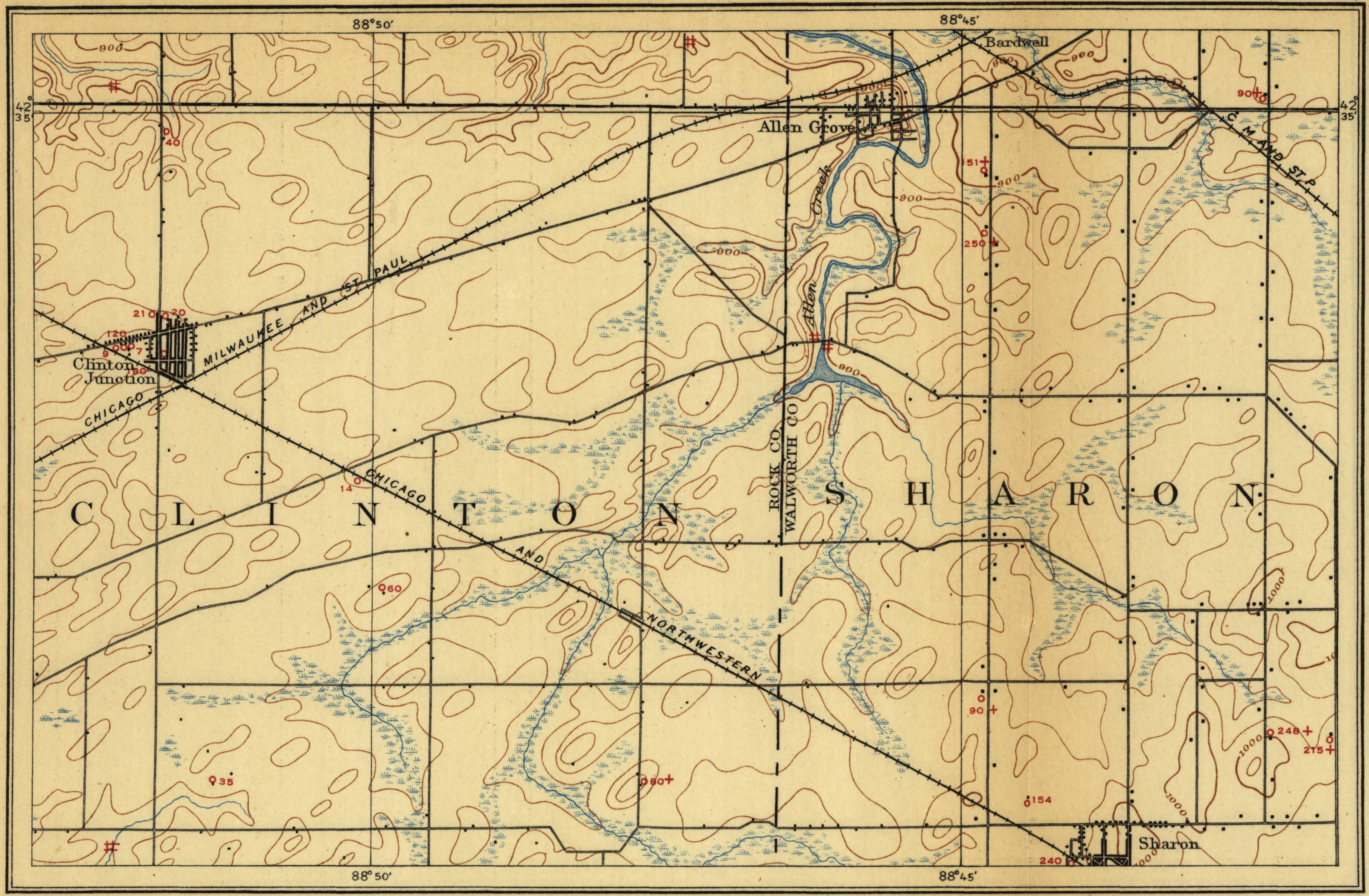
	Feet.
Brown clay with included scattered small chert and crystalline pebbles	1–1½
Reddish-brown gritty drift with etched and rotten limestone pebbles	1–1½
Buff, partly leached, pebbly limestone till	2

A little farther up the slope the brownish material was absent, having been removed by wash so that the buff till reached the surface. The variation in the thickness of the weathered zone depends on the texture of the drift and also on the relative rates of alteration by weathering or removal by surface wash. In some places where the drift was loose and sandy the depth of the leached zone was considerably more than where there was a clay matrix. Oxidation of the iron ingredients has in most places changed the original color of the drift to a brownish or a yellowish-brown to a depth about as great as that of the leaching or to somewhat greater depth. Generally the upper one-half to 1½ feet is bleached to a dirty gray. Over the whole is a goodly coating of black humus, giving a warm, loose, loamy soil. The gray zone is deeper as the humus layers become thicker. The degree of the leaching and oxidation shows an exposure to the weather considerably larger than that of the moraine-bordered drift of the region.

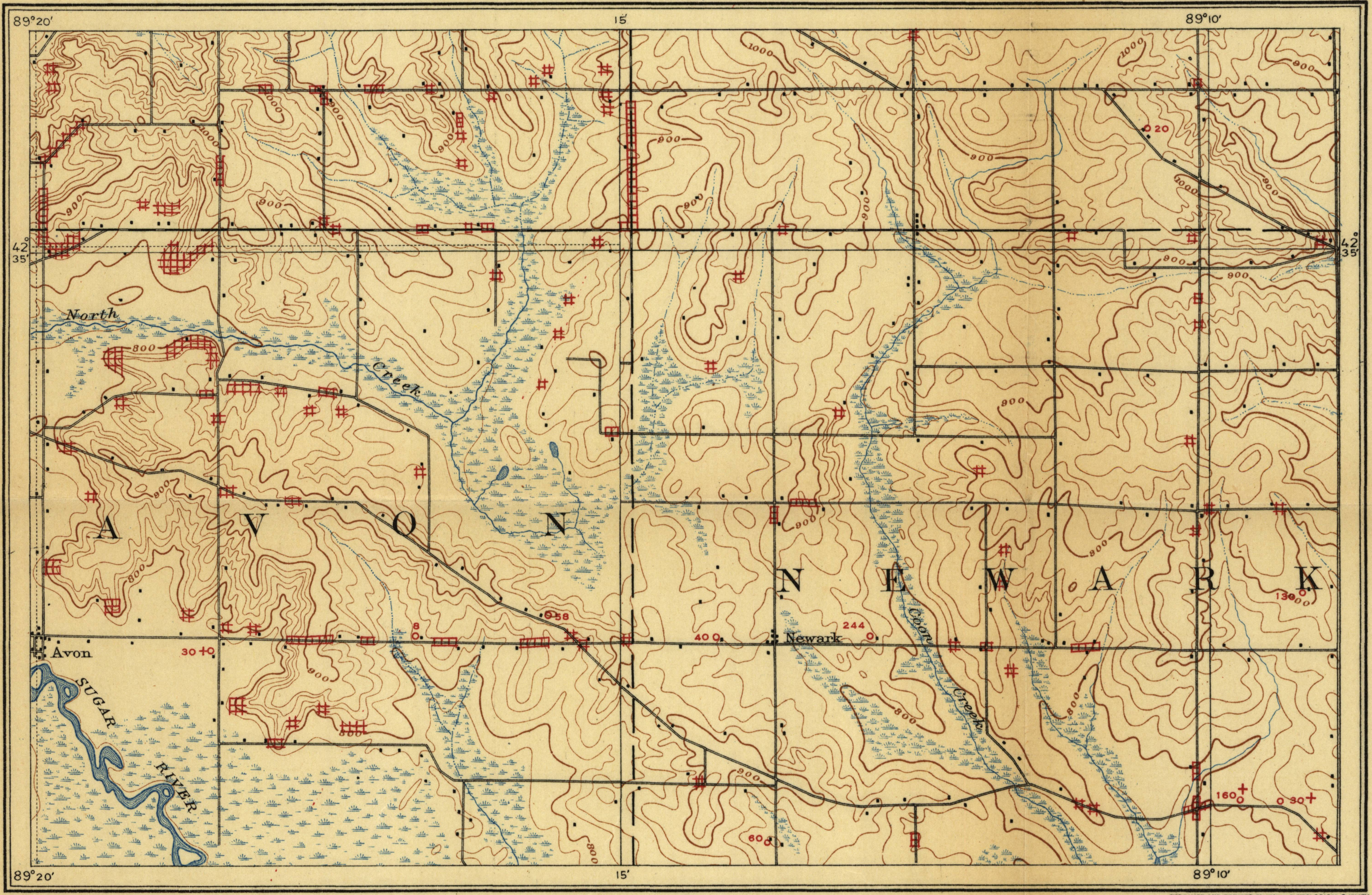
LITHOLOGIC COMPOSITION.

The pebbles included in the drift of this tract are principally of local derivation. It is not everywhere possible accurately to assign all the limestone pebbles to their parent formations, for the identification must be made on the basis of lithologic character and there is more or less gradation from one type to another, but the distinction can usually be made fairly well.[1] Estimates made at several of the exposures of this older drift, the averages of which are shown in the accompanying table, showed that nearly 81 per cent of the coarser stony material is of limestone.

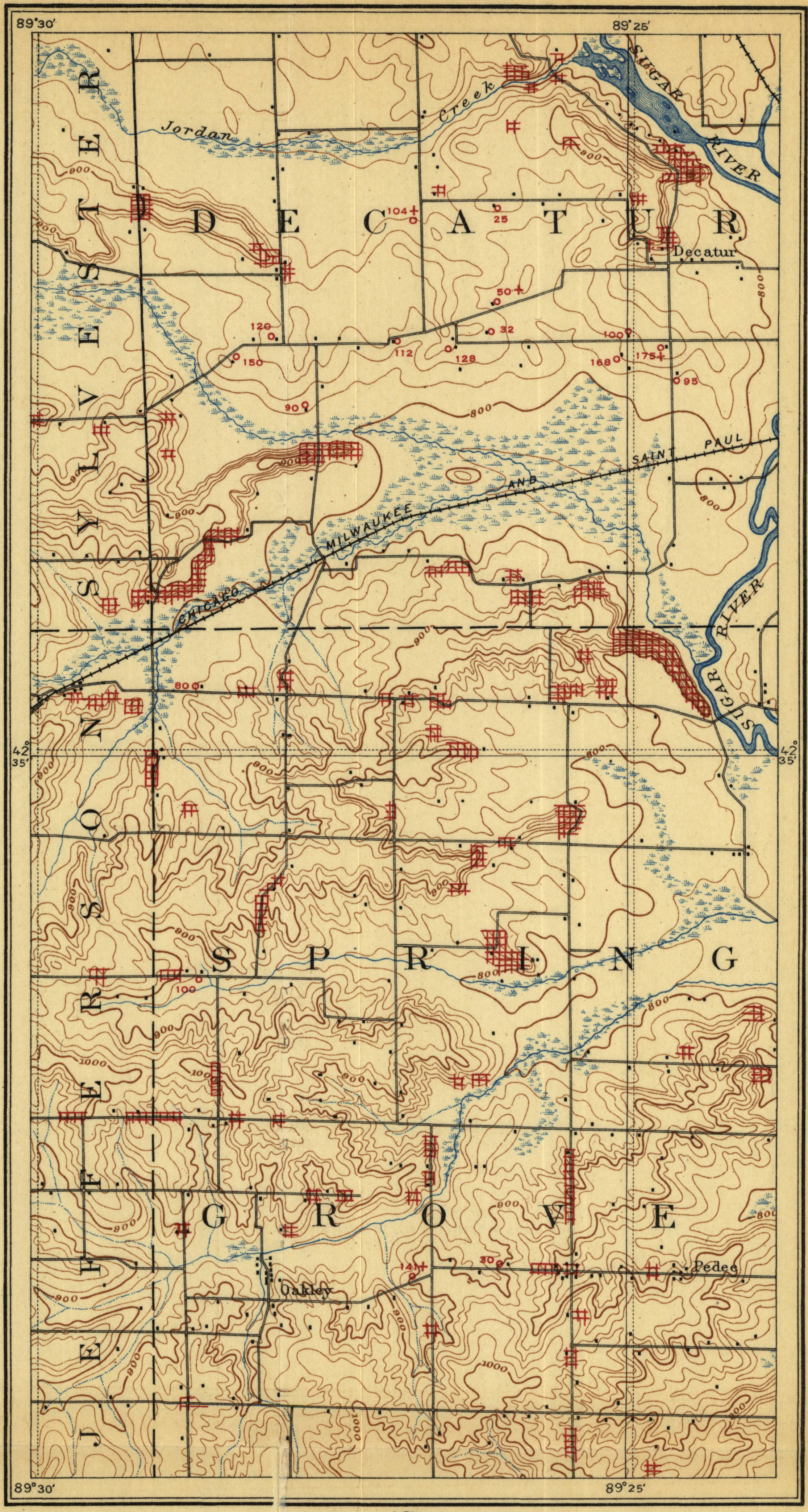
[1] The term "limestone" used in the discussion of the glacial deposits includes dolomite, as these two materials have not generally been discriminated.



(A)



(B)



(C)

LEGEND

Exposures of limestone and sandstone which indicate that the covering of glacial drift is very thin

100 o Thickness of glacial drift determined by well borings that reached bedrock

100 +o Thickness of glacial drift penetrated by wells that did not reach bedrock

ENGRAVED AND PRINTED BY THE U.S.GEOLOGICAL SURVEY

Bases from Shopiere, Delavan, Brodhead, and Janesville topographic maps

MAPS OF PORTIONS OF WALWORTH (*A*), ROCK (*A and B*), AND GREEN (*C*) COUNTIES, WIS.

Showing topography and thickness of the glacial deposits

T. C. Chamberlin, geologist in charge
Geology by Wm. C. Alden
Surveyed in 1900 and 1901

Scale $\frac{1}{62500}$

1 ½ 0 1 2 3 4 Miles

1 ½ 0 1 2 3 4 5 Kilometers

Contour interval 20 feet.
Datum is mean sea level.

1917

Average lithologic composition of pebbles of pre-Wisconsin drift east of Rock River, Wis.

	Per cent.
Niagara, Galena, and Trenton limestones	80.79
Chert, mostly from local limestone	1.70
St. Peter and Cambrian sandstone	1.83
Huronian quartzite	.14
Crystalline rock	14.50
Doubtful, mostly limestone	1.00
	99.96
Percentage of foreign material	16.47

At some exposures the greater part of the limestone pebbles were from the Galena and at others the large majority was from the Niagara. The high percentage from the Niagara indicates an easterly derivation for the drift. Of the sandstones, quartzites, and crystalline pebbles estimated to be of foreign derivation, only 19.15 per cent could not have been derived from rock beds within less than 25 miles of the places of their deposition. No representatives of the "Cincinnati" shale were recognized among the coarser material. It is probable, however, that owing to their soft and friable character, the contribution from these beds is to be found almost entirely in the finer clayey parts of the drift, where they are less easily distinguished.

Of these pebbles and bowlders the foreigners are nearly all well rounded. Of the local limestones, the Niagara is generally much more worn than the Galena, which is largely in angular or little-worn fragments. The pieces are usually clean and fresh looking, and the Niagara pebbles especially show polished and striated surfaces. At a few of the exposures a part of the pebbles have a yellowish or brownish coating of iron oxide, and the crystalline pebbles are disintegrating. These apparent evidences of age, however, are but little more marked than have been observed at some of the exposures in the later drift area.

No attempt has been made to identify the different species of igneous and metamorphosed crystalline rock represented in the pebbles and bowlders within the drift and sprinkled so generally upon the surface. They range in character from granites to diorite and diabase, with much gneiss and various schists, the more basic varieties predominating. Blocks of quartz porphyry, which are especially noticeable on account of their bright-red color, are plentiful; one block of greenish, schistose, quartz-pebble conglomerate was seen in the village of Sharon; and some pebbles of quartzite occur that closely resemble the quartzite of the ledges of the Waterloo region in southern Dodge and northern Jefferson counties. In many places blocks of Niagara dolomite lie upon the surface.

A large part of these surface bowlders show the effects of prolonged exposure to the weather. The crystallines, especially the more basic varieties, are oxidized to such a degree that shell-like pieces one-eighth to one-fourth inch in thickness may frequently be broken off by light blows of the hammer. Some show incipient cracks. The most marked contrast between the bowlders of this and the moraine-bordered drift areas is the condition of the bowlders of the Niagara dolomite. In the later drift areas these show fresh, clean surfaces such as are seen on pebbles which have been taken but recently from the body of the drift. Niagara bowlders that have been exposed on the surface since the older drift was deposited would hardly be recognized at first glance. Their surfaces, instead of being fresh, white, and smoothly polished or glistening with crystal facets, are dull grayish to buff, granular, and in many cases grotesquely irregular, with solution pits extending nearly or quite through them. Fresh fractures, however, reveal the whitish crystalline Niagara dolomite, unmistakable even where fossils are not present. This evidence of long exposure is unquestionable.

TOPOGRAPHY.

For the purpose of illustrating the difference in topography of different parts of the pre-Wisconsin drift area of Walworth, Rock, and Green counties, Wis., portions of the Shopiere, Janesville, and Brodhead topographic sheets are presented. Plate XV, *A*, illustrates the topography and thickness of the drift in portions of the towns of Clinton and Sharon in the tract under discussion east of Rock River. Topographically the tract is a gently undulating drift plain set with numerous low elliptical hills, first recognized as drumlins[1] by I. M. Buell. Its surface has been modified only slightly by erosion.

[1] On the maps illustrating The Delavan lobe of the Lake Michigan glacier (U. S. Geol. Survey Prof. Paper 34, 1904) these drumlins were not differentiated from the rest of the pre-Wisconsin ground moraine.

THICKNESS.

Either the Illinoian drift is much thicker in this part of the area north of the State line than south of it, or else the combined thicknesses of two or more drift sheets are present in this part of Wisconsin.

Of 49 wells in the towns of La Prairie, Bradford, Turtle, and Clinton, concerning which information was obtained, 44 reached rock at depths of 4 to 144 feet, with an average of 36 feet of drift, and the remaining 5, in the towns of Turtle and Clinton, did not reach rock at depths of 40 to 140 feet. In the western half of this tract numerous rock exposures occur. As the surface of the rock slopes eastward, however, the drift thickens, so that in the town of Sharon, of 21 wells concerning which data were obtained, 18 failed to reach rock—8 at 28 to 98 feet, 7 at 105 to 176 feet, and 3 at 215 to 250 feet. Only 3 were reported as reaching the limestone—the village and creamery wells at Sharon, in which the rock was encountered at 217 and 242 feet respectively, and a well about 3 miles northeast of Sharon, in which there was said to be 248 feet of drift.

The thickness of drift penetrated by many of these wells, together with certain other phenomena, suggest but do not confirm the possibility of more than one drift sheet. In L. Roth's well, 1½ miles northeast of Sharon, the following sequence is said to have been penetrated:

Log of Mr. L. Roth's well, NE. ¼ sec. 27, T. 1 N., R. 15 E. (Sharon Township).

	Feet.
Clay	30-40
Sand	60-70
Clay	148
Depth	248

This sequence suggests that the two deposits of till separated by water-laid material belong to distinct stages.

BURIED VEGETAL DEPOSITS.

The occurrence of buried vegetal deposits has been reported at a few points, but the data are insufficient to establish the presence of an interglacial soil.

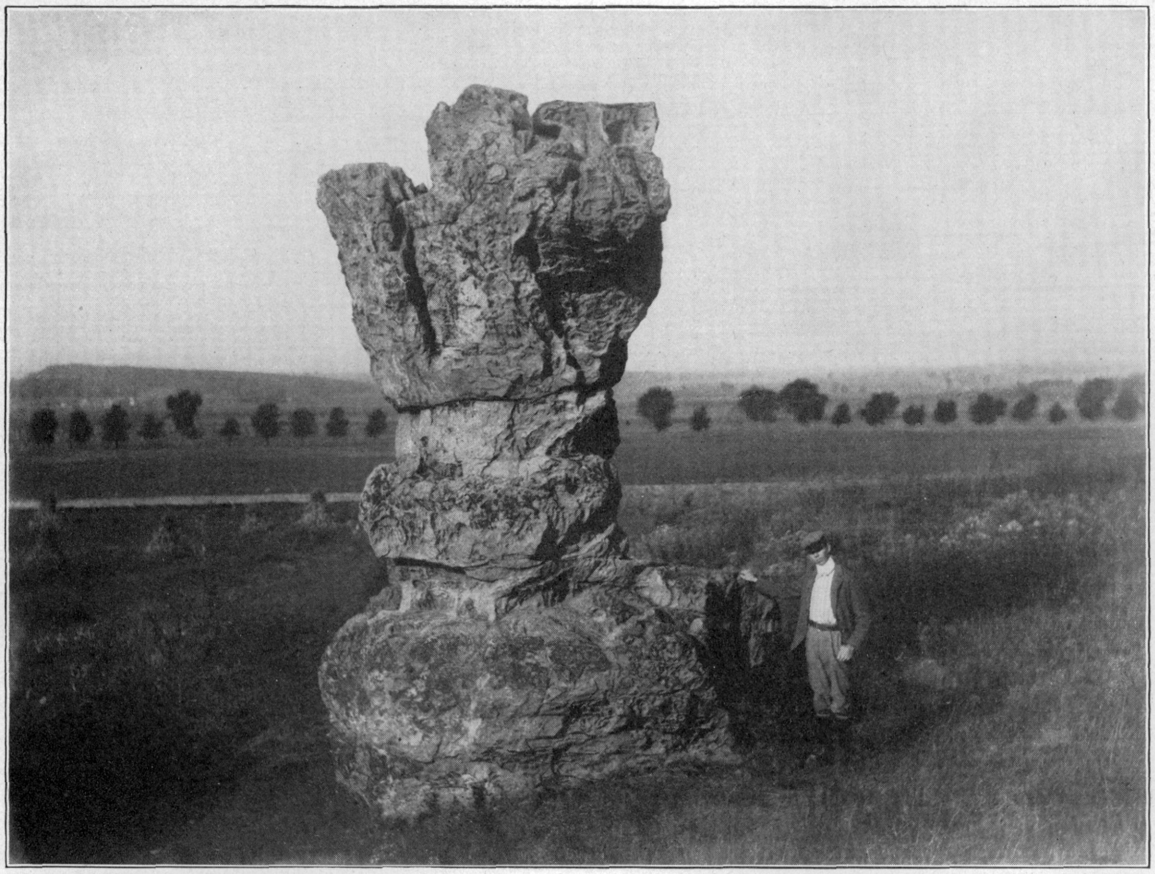
Mr. Conree's well, in the NE. ¼ sec. 27, T. 1 N., R. 14 E. (Clinton Township), is said to have penetrated a deposit of black muck, which may account for the trouble in obtaining good water from this well, and H. A. Ravenum's well, in the NE. ¼ sec. 35, T. 1 N., R. 13 E. (Turtle Township), penetrated a similar deposit. In neither well, however, could the exact depth of the muck be ascertained. Driftwood is reported from a well in the SW. ¼ sec. 25, T. 1 N., R. 15 E. (Sharon Township), but it was not learned that it was connected with any soil horizon. Rotten wood was reported in the creamery well at Sharon at a depth of 210 feet, below which was 3 feet of black muck lying on limestone. It is said that the water at the time of drilling this well had an odor like marsh water.

PRE-WISCONSIN DRIFT IN TRACT BETWEEN ROCK AND SUGAR RIVERS.

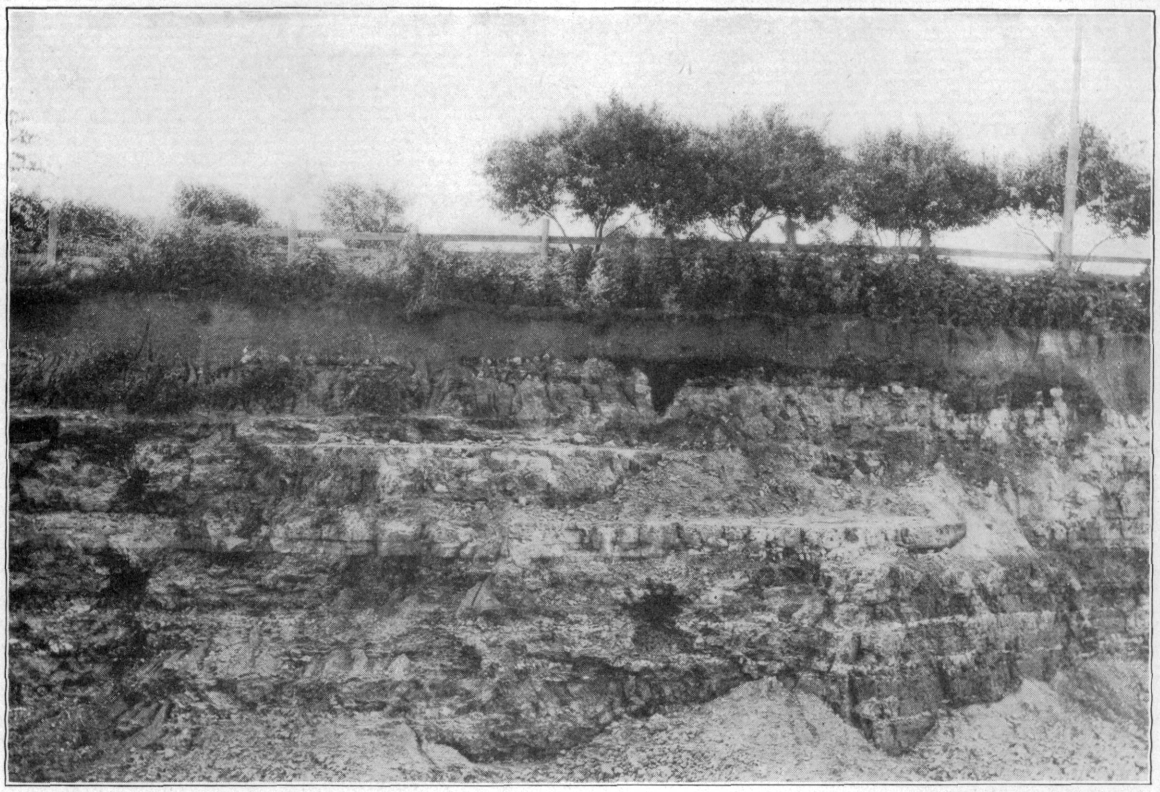
EVIDENCE OF AGE.

In the upland tract between Rock and Sugar rivers, which is mantled by pre-Wisconsin drift, the rock formations rise markedly. East of Rock River the preglacial eroded valleys lay almost entirely in the Galena dolomite and Trenton limestone, but west of the river the Galena was almost entirely removed and the streams had cut down into the St. Peter sandstone, where more rapid erosion was possible and the slopes were more dissected. Plate XV, *B*, represents the present topography of drift-mantled portions of the towns of Avon and Newark and the thickness of the drift in the tract between Rock and Sugar rivers. Except in valley bottoms, whose marshy condition is due in part to blocking of the drainage in the lower courses by outwash from the later glaciers, the topography appears somewhat more mature than that shown in Plate XV, *A*. This difference, however, seems to be due rather to the underlying preglacial topography than to the amount of erosion since the glaciers disappeared. West of Rock River the drift coating is generally thin on the crests and higher slopes of the ridges, so that the underlying rock is exposed at the surface or in very shallow cuts at nearly every point where a road crosses a crest, yet numerous wells in the valleys are reported to have penetrated 60 to 240 feet of drift before reaching rock.

In sec. 18, T. 1 N., R. 11 E. (Newark Township), one of the valleys tributary to the ancient Coon Creek valley has been entirely cut off by a dam of drift, and its headwaters have been cap-



A. ROCK PILLAR, ST. PETER SANDSTONE, NEAR FOOTVILLE, ROCK COUNTY, WIS., THE RESULT OF POST-ILLINOIAN WEATHERING.



B. GALENA DOLOMITE EXPOSED IN ILLINOIS CENTRAL RAILROAD CUT EAST OF MONROE STATION, WIS.

The surface is deeply weathered and overlain by residual clay and brown loamy clay. Drift is absent or nearly so.

A. MATURE EROSION TOPOGRAPHY ON GALENA AND TRENTON DOLOMITES IN DRIFTLESS AREA NORTHWEST OF MONROE, WIS.

Very little if any of the upland remains not reduced to slope.

B. MATURE EROSION TOPOGRAPHY ON GALENA AND TRENTON DOLOMITES THINLY COVERED WITH ILLINOIAN DRIFT 3 MILES EAST OF MONROE, WIS.

Very little if any of the upland remains not reduced to slope.

tured by North Creek and drawn off westward to Sugar River. (See Pl. XV, *B*.) The crest of this drift dam, however, lies 40 to 140 feet below the level of the divides surrounding the basin. In the northwest part of sec. 26 a minor tributary of this same valley is blocked by a drift dam, on whose crest, within one-fourth mile of a rock exposure, a well penetrated 160 feet of drift without reaching the bottom of the ancient valley. Above the dam the valley is broad and open. The postglacial drainage has been diverted to one side and has cut a channel about 20 feet in depth through the narrow ridge of limestone to drain the basin shut in by the dam. The crest of this drift dam lies 120 to 160 feet below the level of the upland crests 1 to 2 miles away. Similar drift dams and drainage diversions in this tract have already been described (see pp. 118 and 119), among them being one in secs. 9 and 16, T. 2 N., R. 12 E. (Rock Township), where there is at least 218 feet of drift filling, as shown in H. Hayner's well, within one-half mile of a rock exposure in the creek bed. A second is in the valley of Stevens Creek in adjacent parts of the towns of Center and Plymouth, 1 to 2 miles northeast of Footville, where there is 140 feet or more of drift fill. A third is in the vicinity of Orford, where a maximum thickness of 212 feet is reported.

From these features it is apparent that the ancient valleys in the tract between Rock and Sugar rivers were never entirely filled with drift, and that by far the greater part of the present relief and apparent maturity of the topography is due not to postglacial erosion but to the strong relief of the preglacial surface which the drift mantled but did not obliterate. The amount of erosion, allowance being made for more rapid work on the steeper slopes, shows no evidence of age greater than that manifested by the drift in the tract east of Rock River.

Even with these qualifications, however, the maturity of the postglacial drainage development on the slopes and crests is distinctly greater than that of the drainage systems within the terminal moraine of the Green Bay Glacier to the north.

In texture and lithologic composition the drift of the tract is much the same as that of the tract east of Rock River, except that it contains somewhat less Niagara dolomite and proportionately more Galena dolomite and Trenton limestone. The pinkish tint is also less frequently noticeable, the upper part being a prevailingly light buff. The degree of leaching, oxidation, and other effects of exposure to the weather is almost the same. There are here no extensive uneroded upland plains like that near Clinton Junction, so there has been greater opportunity for surface wash, and this has removed some of the weathered part of the drift from the higher slopes and concentrated it in the lower tracts. In consequence there is somewhat greater variation in the results of tests at different points, but the average result is almost the same. At a few places in both tracts some gravels are coated with brownish iron oxide, but most of the pebbles are fresh, clean, and sound. At one point in the town of Janesville gravels partly cemented together by lime were found. In Coon Creek valley, in the town of Newark, and between Coon Creek and Sugar River valleys there are considerable deposits of sand, which in some places resemble a morainal deposit and in others resemble dunes of sand blown up from the Sugar River bottom.

One indication of the lapse of a considerable geologic interval since the glaciation of this tract is the occurrence in the NE. ¼ sec. 31, T. 3 N., R. 11 E. (Center Township), a mile northwest of Footville, of a rock pillar of St. Peter sandstone, smaller in size but resembling in character the towers and castle rocks of the Driftless Area. (See Pl. XVI, *A*.)

The pillar, which stands about 10 yards from the low sandstone slope, has a height of about 15 feet and a maximum diameter at the base of 10 or 12 feet, and has been developed by the erosion, or disintegration and removal, of the sandstone which originally connected it with the adjacent slope. The significant feature is that the isolation of the pillar, which in this particular position must have taken considerable time, has evidently been accomplished since the glaciation of the area, as it is inconceivable that such a small tower could have withstood the abrasion of the vast amount of ice which passed over this spot when the glacier was advancing to the limit of the drift area.

The effect of the overriding of such rock towers as stood in the way of the advancing ice is illustrated near the west line of the NW. ¼ sec. 22, T. 2 N., R. 10 E. (Spring Valley Township), where a disturbed mass of Trenton limestone was evidently pushed bodily from the adjacent ridge into the ravine through which the road descends the slope. The mass lies 50 to 60 feet below the top of the sandstone in the adjacent ridge.

MORAINAL DEPOSITS.

The mild drumloidal features noted east of Rock River are absent in the tract between Rock and Sugar rivers, and their places are taken by morainal deposits disposed partly in well-defined morainal ridges and partly in irregular scattered tracts without definite trend.[1] The disposition is such as to make it uncertain just which morainal deposits are to be correlated as marking any given position of the ice front. There is, however, something of a general northwest-southeast trend nearly at a right angle to the trend of the axes of the drumloidal features east of the river and to the striæ observed by Buell, Chamberlin, and the writer on the rock surfaces at several places.

The best defined of the morainal ridges extends northwestward from the vicinity of Beloit. A map and description of a portion of this moraine have been published by Chamberlin.[2] Except for several narrow breaks a few rods wide this moraine may be traced from the western part of the city of Beloit as a continuous narrow, sinuous, esker-like ridge, running north-northwest up and down and along slopes and over crests of the rock ridges to the marshy creek valley at the north line of the town. The ridge, which is shown by several exposures to be composed of sand, coarse gravel, and bowlders, varies in height from 10 to 40 feet and in width from 100 feet to 40 rods or more. An effort to trace the moraine farther northward and northwestward did not meet with very much success; other gravel deposits do occur, as shown on the map, but their contours and orientation are, in general, much less clearly defined, and their distribution is such as to make their correlation uncertain, though perhaps not more uncertain than the correlations suggested for some of the morainal deposits of the Wisconsin stage.

About a mile west of Footville a similar sharp, narrow, esker-like ridge of gravel and sand rises above the marsh bottom of the valley and extends with some breaks about 2 miles up the valley parallel with the railway; north of the divide two small morainal tracts rise above the marshy flat, and 2 miles southwest of Evansville similar gravel deposits occur, all of which might perhaps be regarded as belonging to one belt of morainal deposition. From the road which runs west from Evansville northwestward to the morainal ridge in sec. 13, T. 4 N., R. 9 E. (Brooklyn Township), there is a considerable thickness of drift. In sec. 30, T. 4 N., R. 10 E. (Union Township), this drift lies against the east slope of the rock ridge with a somewhat definite margin, as though it marked the position of the ice front at a certain stage. This slight marginal ridge has held the surface drainage up along the slope and caused it to cut a small gorge in the limestone crest at Arthur Spencer's quarry, in the NE. ¼ sec. 31, through which the waters escaped down the valley to the west. The surface of the drift in this tract shows erosional rather than morainal contours.

Other tracts mapped as morainal show considerable deposits of gravel, and in places the surface is knolled and pitted as, for example, in the tracts northwest of Orford and east of Footville. The original configuration, however, has in most places been much modified by erosion. This is particularly true along the north slope of the upland south of Marsh Creek in Janesville Township, where the surface has been so eroded that it is difficult to determine the actual bounds of the very considerable deposit of gravel. This is in marked contrast with the terminal moraine of the Wisconsin stage 1 to 2 miles to the north, whose surface has been scarcely at all modified. Wells have penetrated this deposit south of Marsh Creek to depths of 50 to more than 200 feet before encountering the rock. The log of one of these wells, that of John Church, is as follows:

Log of John Church's well in sec. 22, T. 3 N., R. 12 E. (Janesville Township).[3]

	Feet.
Sand and gravel	100±
Red clay	10
Pebble conglomerate	⅔
Sand and gravel	40-50
Limestone and sandstone	44-54
	204

[1] On the maps illustrating The Delavan lobe of the Lake Michigan glacier (U. S. Geol. Survey Prof. Paper 34, 1904) and in The drumlins of southeastern Wisconsin (U. S. Geol. Survey Bull. 273, 1905) the terminal or marginal morainal deposits were not differentiated from the ground moraine in the area of pre-Wisconsin drift west of Rock River.

[2] Chamberlin, T. C., Geology of Wisconsin, vol. 2, fig. 10, p. 217, 1877.

[3] From notes of Frank Leverett, to whom the data were furnished in 1886 by L. M. Wilson.

It has been suggested that these morainal deposits west of Rock River mark the limit of one of the major advances of the Pleistocene glaciers and that these deposits and the ground moraine marked by drumlins east of the river belong to a stage of glaciation distinctly later than the drift farther west. This interpretation has been kept in mind during the examination of the drift and during reexaminations of parts of the area, but the writer has not been able to bring himself to accept this view. It has seemed to him that the differences of character, relations, and degree of surficial modification between the drift of these western morainal tracts and that of the morainal deposits east of Rock River were not sufficiently marked to indicate deposition at distinct stages of glaciation separated by an interval of deglaciation of the first rank. He is rather inclined to the idea that the morainal deposits mark positions of halt during one of the minor oscillations of the ice front following the maximum extension at the Illinoian stage of glaciation and corresponding in magnitude to those marked by the inner recessional moraines of the Green Bay Glacier of the Wisconsin stage.

LITHOLOGIC COMPOSITION.

A careful lithologic examination of the pebbles of the drift in the tract between Rock and Sugar rivers at 30 different exposures, most of them in the morainal deposits described above, shows the following average composition:

Average lithologic composition of pebbles of pre-Wisconsin drift between Rock and Sugar rivers, Wis.

Niagara dolomite	19.68
Galena dolomite and Trenton limestone; Lower Magnesian limestone	53.51
Chert, mostly from local limestone	2.26
St. Peter and Cambrian sandstone	2.65
Huronian quartzite	.53
Crystalline rocks	11.81
Doubtful, mostly limestone	9.50
	99.94
Percentage of foreign material	11.81

The bowlders on the surface show about the same variety as those east of Rock River. In sec. 15, T. 2 N., R. 11 E. (Plymouth Township); secs. 9 and 18, T. 1 N., R. 11 E. (Newark Township); sec. 22, T. 3 N., R. 12 E. (Janesville Township); and a few other places, bright-red quartz porphyries like those in the vicinity of Sharon were seen.

Quartzite bowlders, although nowhere abundant, are not scarce and have aroused considerable speculation as to their derivation. Those observed by the writer vary in color from white, through gray, greenish gray, bluish gray, grayish purple, purple, banded purple, pink, and red. Most of them are less than a foot in diameter, but at least one 2 to 3 feet long was seen. Many closely resemble rock exposed in the ledges near Waterloo, Wis., and are regarded by some [1] as having been derived directly from these ledges.

When the drift of this tract was first studied by Chamberlin [2] the presence of these bowlders and the similarity of many of them to the quartzite of the Waterloo ledges was noted and was regarded as evidence that the Green Bay Glacier had advanced southward into Illinois, bringing these pebbles and bowlders. Later, however, Chamberlin began to doubt this interpretation, which seemed to conflict with more decisive evidence that the earlier glacial movement was westerly across this tract.

EARLIER DRIFT AND BURIED VEGETAL MATERIAL.

The writer knows no certain evidence of the presence of underlying earlier glacial drift. Cemented beds of sand and gravel and underlying consolidated material penetrated in a few wells at some depth from the surface are not improbably, though not certainly, associated with an earlier stage of glaciation. Such a bed is the pebble conglomerate and underlying sand and gravel penetrated by John Church's well in sec. 32, T. 3 N., R. 12 E. (Janesville Township), beneath 110 feet of drift. Mr. Horn, driller, Brodhead, informed the writer that in drilling a well for Mr. Highby in the W. ½ sec. 28, T. 4 N., R. 10 E. (Union Township), he found between depths of 75 and 175 feet cemented sand layers alternating with 15 to 20 foot beds of loose sand. Similar cemented material was encountered in W. E. Hatfield's well in the NW. ¼ sec. 29 of the same township. In the lower 100 to 140 feet wood was mixed with the sand, and the water from a depth of 140 feet was black with fine vegetal matter. Mr. Horn states that wood was encountered at a depth of 80 to 90 feet in a well in the SW. ¼ sec. 18. A well in the NE. ¼ sec. 12, T. 2 N., R. 11 E. (Plymouth Township), is reported to have penetrated at a depth of

[1] Buell, I. M., Bowlder trains from the outcrops of the Waterloo quartzite area: Wisconsin Acad. Sci. Trans., vol. 10, pp. 496-500, 1895.
[2] Chamberlin, T. C., Geology of Wisconsin, vol. 2, p. 202, fig. 3, and pl. 7, 1878.

about 80 feet 10 to 15 feet of black clay lying on 30 feet or so of gravel. Possibly with these deposits should be grouped those penetrated by the city well at Brodhead[1] in the bottom of the Sugar River valley. This well passed through black sandy loam 4 feet, very hard yellow clay 2 feet, yellow clay and quicksand 12 feet, yellow clay, blue gravel, and coarse red sand 6 feet, and sand 2 feet, and entered rock at 136 feet.

PRE-WISCONSIN DRIFT IN TRACT WEST OF SUGAR RIVER.

TOPOGRAPHY.

The topography of the area west of Sugar River, which is mantled with the pre-Wisconsin drift, is well illustrated by Plate XV, *C* (p. 138). Taken as a whole the region is maturely dissected by erosion. Scarcely an acre of upland remains undrained and in many places the tips of the erosion lines have notched the crests, as, for instance, in the region of Monroe (Pl. XVII, *B*), where the upland slopes of the limestone area are marked by drainage lines at intervals of 10 to 40 rods, giving smoothly rounded slopes. This topography is very similar to that in neighboring parts of the Driftless Area (Pl. XVII, *A*). The maturity of the drainage system and the consequent thorough dissection of the indurated rock formations is shown on the map. (See Pl. I, in pocket.) Where the preglacial streams had cut their valleys down into the St. Peter sandstone the lower slopes are steep and in many places abrupt, like bluffs, above which rise the gentler slopes of the limestone caps. Where the Galena and Trenton were almost entirely removed, narrow ridges and flat-topped buttes occur between broader, gently undulating tracts underlain by the friable sandstone. As the southward dip of the rock formations is steeper than the grade of the main streams, these valleys reach the Lower Magnesian limestone in Sylvester and Washington townships, and thence northward. The surface of this formation is very uneven (see pp. 82 and 83), being in fact an ancient eroded land surface which was later submerged and buried by the St. Peter sandstone. In many of the broader parts of the valleys the sandstone has been stripped from the crests of the ancient hills, leaving only low scattered knolls of sandstone and of limestone.

Though the topography as a whole is one of mature erosion, it is evident that almost all the dissection occurred prior to the deposition of the drift. This is seen in the fact that most of the valleys have flat alluvial plains underlain by deposits which they are but now beginning to erode, and in the further fact that at several places broad valleys have been blocked, and the streams in these places have shifted to one side and have cut short, sharp, narrow gorges in the rock, returning to broad, open valleys a short distance below the obstructions. The most notable example of this is 2 miles south of Browntown (see pp. 121 and 122), where the broad, flat bottomed valley of Pecatonica River, one-half to 1 mile in width, is blocked for a mile by a broad ridge 50 to 60 feet in height, past which the stream flows through a narrow, newly cut gorge. Below this dam the stream again flows in the open valley for nearly 2 miles, where it is again blocked at the State line and forced into a narrow gorge east of Martintown. Similar stream diversions on smaller scales are seen at several places.

LIMIT OF GLACIATION.

As far west as the limit shown on the map by the sinuous line drawn through the towns of Verona, Montrose, Exeter, Washington, Monroe, Clarno, Cadiz, and Wayne there are found evidences of Pleistocene glaciation. Scattered crystalline pebbles foreign to the area lie west of this limit, but these were probably transported beyond the glacial front by ice blocks floating on lakes held temporarily by the glacier occupying the lower parts of the several valleys. No deposits have been observed which show clearly that the ice extended beyond this line. Through most of this distance the limit of the advance can be only approximately determined, as along this border the drift generally thins to a feather edge of scattered pebbles with here and there isolated deposits of till or gravel which show that the ice must have extended thus far.

In 1862 Whitney[2] discussed the absence of drift and bowlders from the southwestern part of the State and concluded that the area was not submerged during the drift epoch. He

[1] Record and samples of drillings in the possession of William Roantree, Monroe, Wis.

[2] Hall, James, and Whitney, J. D., Report on the geological survey of Wisconsin, vol. 1, pp. 137-139, 1862.

notes as a single exception the occurrence of a group of loose blocks of sandstone at one place on the surface near Mineral Point at an elevation of 125 feet above the sandstone formation. He writes, in part, as follows:

> There can be no doubt that these masses of sandstone have been raised, either artificially or by natural means, 125 feet above their original place of deposit; a circumstance which would be of easy explanation if the drift had ever swept over this region; but as this is not the case, as has been already shown, the solution of the problem of their transportation is much less simple. * * *
>
> The only natural agents capable of effecting these changes of position of large fragments of rock are either currents of water or floating ice masses. But to apply either of these causes in this case it would be necessary to make the phenomenon a strictly local one, since there is nowhere else in the region any evidence of either currents or transportation by ice. It is not impossible that ice having been formed in the bottom of the valley a damming up of the outlet may have taken place, so as to raise the stream, form a temporary lake, and thus float sheets of ice having masses of sandstone attached to them up to the present level at which they are deposited, where they would be left when the barrier gave way and the water was drained off. Since there is but little in the shape of the ground * * * to favor this idea, inasmuch as the neighboring valley is in no respect differently formed from any other in the neighborhood, this is only suggested as a possible explanation.

Although the conditions resulting in the damming of the Pecatonica Valley were somewhat different from those that Whitney had in mind inasmuch as he referred the deposition of the drift to diluvial rather than glacial action, yet his suggested explanation is probably much nearer the truth than he supposed. The blocking of the Pecatonica Valley by the ice sheet south of the site of Browntown would pond waters in each of the tributary valleys and would raise the water level until an outlet was found across the lowest point in the rim of the basin. The outlet was probably in or adjacent to the southern part of T. 1 N., R. 4 E. (Gratiot Township), whence the waters escaped southwestward to Apple River. The writer is not informed as to the exact elevation of either this outlet or of the lifted sandstone blocks, but unless the blocks are too high on the slope it is clear that, were they incased in masses of ice, the rising water in this temporary glacial lake might have lifted them to their present positions.

DRIFT BORDER.

The character of the drift phenomena along the border of the glaciated area is described by townships, beginning at the north.

Verona Township (*T. 6 N., R. 8 E.*)—Three miles northwest of the village of Verona, in adjacent parts of secs. 4, 5, 8, and 9, the terminal moraine of the Green Bay Glacier is bordered on the west for about a mile by a flat terrace 250 rods in width, on which a thin deposit of gravel with scattered bowlders overlies limestone. The gravel may be in part at least older drift and in part outwash from the Green Bay Glacier. In sec. 16 a sharp, narrow ravine, whose west slope is of thinly covered limestone, borders the abrupt west front of the terminal moraine. Drift which could not have come from the moraine is thinly scattered over the ridge west of this ravine. Two miles west of Verona and one-fourth mile north of the road a small valley appears to be entirely blocked by a filling of drift, and the drainage has turned abruptly westward and has cut a narrow gorge 35 to 40 feet in depth through the bordering limestone ridge. A gully in the south slope of the drift dam exposes a little sandy till and crystalline pebbles beneath 3 to 4 feet of brownish loamy clay.

On the hill a mile south of Verona (S. ½ sec. 22) a road cut exposes 6 feet of glacial gravel probably not belonging to the moraine of the Green Bay Glacier, which lies just across the narrow valley on the east. Thence southward to Paoli only scattered pebbles and bowlders were noted outside of this moraine.

Montrose Township (*T. 5 N., R. 5 E.*).—On the east side of Sugar River, northeast of Paoli in sec. 2, occur low knolls and swells of drift. Excavations in these expose 15 feet of poorly assorted gravel and of interstratified clay and gravel in which only a very small percentage of the pebbles are foreign crystallines. Thin drift occurs on the ridge east of Sugar River, but very few scattered crystalline pebbles were seen west of the broad terrace bordering the stream, which is composed of sand and gravel washed out from the later glacier, until a point a mile northwest of Belleville is reached. At this place (NE. ¼ sec. 33) there are low undulations, one at least of which is shown by James Jeans's gravel pit to be composed of glacial drift, poorly assorted morainal gravel, and till 20 to 25 feet deep. At one point a mass of dense, stony till extends vertically through the section and is said to have extended clear through the hill with thicknesses varying from 1 to 8 feet. This till is fresh looking, brownish to pinkish in color, and highly calcareous.

Exeter Township (*T. 4 N., R. 8 E.*).—Wells in the southern part of secs. 10 and 15, and in the W. ½ sec. 23, 1 to 2 miles west and southwest of Dayton, penetrate 20 to 130 feet, principally of sand and blue clay, in a belt about a mile wide between exposures of sandstone and limestone, showing that a considerable filling of drift entirely blocks a preglacial valley, which was tributary to Sugar River 1 to 2 miles south of Dayton. Northwest of this drift dam a broad, flat lacustrine-like plain extends 3 to 4 miles up the valley. The present streamlet drains the basin northeastward through a narrow cut in the crest of the low sandstone ridge near the railway a mile south of Belleville. A few scattered pebbles west of the railway may have been carried there by ice floating on a lake which occupied the upper part of the basin.

The lowest point on the divide between the head of Sugar River basin and the Black Earth Valley on the north in the SE. ¼ sec. 16, T. 7 N., R. 7 E. (Cross Plains Township), is 1,100 feet above sea level. That between the upper Sugar River basin and the Little Sugar River basin is 1,000 to 1,050 feet above sea level, in sec. 18, Exeter Township, and in sec. 31, Montrose Township. The lowest part of the divide between the valleys of Little Sugar River and Skinner Creek (a tributary of Pecatonica River) in the southwestern part of Washington Township, is 1,050 to 1,100 feet above sea level. So the ice-ponded water at its maximum extension must have formed a continuous lake in the upper parts of Sugar and Little Sugar river basins with an elevation between 1,050 and 1,100 feet above sea level, and probably discharged southwestward to a similar lake in the Pecatonica basin.

Glacial gravels occur at Exeter and a thin coating of till lies on the crest of the ridge one-half mile to the southwest. Three miles northwest of Exeter, in sec. 28, scattered crystalline pebbles occur on the highest part of the crest of the ridge between Sugar and Little Sugar basins at an elevation of 1,050 to 1,100 feet above sea level. It is possible that these erratics may have been carried to this position on floating ice blocks, though it is not certain that the crest was entirely submerged. If not, the glacier must have extended thus far. No other erratics have been observed in this basin at higher elevations. A few have been noted at lower levels in the eastern part of T. 4 N., R. 7 E. (New Glarus Township) and several in the valley in the southwestern part of Exeter Township. From the vicinity of Exeter the glacial margin appears to have extended southwestward to the northwestern part of Mount Pleasant Township and the northeastern part of Washington Township.

Mount Pleasant Township (*T. 3 N., R. 8 E.*).—There are indications of the partial blocking of Little Sugar River valley by a filling of drift in sec. 5, 2 miles northeast of Monticello; and the south slope of the ridge in sec. 6, a mile north of the village, shows a thin coating of till.

Washington Township (*T. 3 N., R. 7 E.*).—For a mile west of Monticello on the south side of Little Sugar River there are low undulations and numerous bowlders, and till is exposed in the road cuts. Apparently the thickness of drift in adjacent parts of secs. 12 and 13 is considerable. Scattered pebbles were seen farther west up the valley, and a few crystalline pebbles were found on the slope at the head of the valley in sec. 18, somewhat more than 1,000 feet above sea level. This must have been near the upper limit of the submergence.

Thin calcareous till lies on the limestone ridge in secs. 13 and 14, and the ice appears to have extended up the valley of the south branch of Little Sugar River into secs. 25 and 35 and perhaps to sec. 22, where, one-half mile east of the German Lutheran Church, a slight till-like deposit is exposed in the road. Scattered crystalline pebbles occur in the upper part of this valley, but none was seen on the higher slopes and crests west of the SW. ¼ sec. 35, where a small pit exposed 7 feet of sandy noncalcareous till over 3 feet of clayey sand.

Drift was penetrated by a well in the NW. ¼ sec. 36, as follows:

Log of E. W. Cheseboro's well, sec. 36, Washington Township.

	Feet.
Black soil, loam, and clay	24
Soft, slushy clay	5
Hard, tough gray clay, apparently without stones	30–35

In the W. ½ SW. ¼ sec. 36 occurs another small example of drift dam and stream diversion. A 30 to 40 foot ridge of drift blocks one of the small drainage lines in the north slope and has forced the interrupted drainage to the east, where it has cut a narrow ravine 40 feet deep through a limestone spur. Clearly the upper part of the valley never was filled with drift, though the ice must have extended at least three-fourths of a mile farther west.

Monroe Township (*T. 2 N., R. 7 E.*).—Southward to Monroe the ice extended westward to and in places slightly across the crest of the divide. Scattered pebbles and bowlders and in places a little till are seen, and in the SE. ¼ sec. 11 a small deposit of poorly assorted glacial gravel remains in the angle between two converging drainage lines. Though the presence of the drift does not manifest itself in the topography thicknesses of 3 to 20 feet of fresh-looking, pinkish, calcareous till are exposed in several of the cuts on the Illinois Central Railroad beneath 2 to 4 feet of brown loamy clay. Several other cuts show no drift or almost none between the loamy clay and the residual chert and limestone. (See Pl. XVI, *B*, p. 140.)

A small deposit of gravelly drift occurs a few rods west of the Illinois Central Railroad station in the north part of the city of Monroe; and wells throughout all but the northwest quarter of the city penetrate drift which ranges in thickness from a layer of scattered pebbles to 85 feet, although its presence is not apparent from the configuration of the surface. About a mile east of Monroe, in the SE. ¼ sec. 36, Mr. Hodge's gravel pit exposes 25 feet of fresh-looking interbedded and cross-bedded sand and gravel, which may be grouped with the marginal drift. As nearly as has been determined the limit of glaciation appears to lie near the Illinois Central Railroad station, the courthouse, and the Chicago, Milwaukee & St. Paul Railway station, and then to extend west-southwest along the south side of the valley traversed by the Chicago, Milwaukee & St. Paul Railway nearly to Browntown.

Clarno Township (*T. 1 N., R. 7 E.*).—The first semblance of a terminal morainal ridge along the drift border south of Verona appears in Clarno Township. Slight swells mark the crest, which in places has a relief of about 70 feet. The ridge is plainly marked for 4 or 5 miles southwest of Monroe, beyond which to Pecatonica River it again disappears in the mature erosion topography. In sec. 4, south of the Chicago, Milwaukee & St. Paul tracks, the ridge blocks the upper part of the Honey Creek valley, wells showing thicknesses of 67 feet of drift. A lake was held in the upper part of the valley west of Monroe and on the melting of the ice a new outlet was cut through limestone and drift in the northwest part of sec. 4. At the railway bridge the narrow gorge is cut 50 feet in limestone, though the buried valley beneath the moraine to the south is nearly 150 feet in depth. At one point limestone is exposed in a gully 70 feet below the crest of the ridge, so that there may be at least this thickness of drift. Silts deposited in the temporary lake furnish the brick clays used at the yards in the northwest part of Monroe. As seen at one point the deposit consists of buff to bluish laminated calcareous clay with streaks of fine gravel, overlain by 1 to 2 feet of black soil. The clay is fairly well leached of its lime to a depth of 3 feet.

Just south of the crossing of the railways west of Monroe the Illinois Central Railroad cuts give a section of this drift ridge nearly three-fourths mile in length. At the crossing 4 to 5 feet of residual clay overlies the limestone with no drift between. A few rods south the drift begins and thickens southward with the rising slope. The following sections show the character of the deposits at several points in these cuts:

Sections of terminal moraine in cuts on the Illinois Central Railroau in sec. 4, Clarno Township.

	Feet.
North part of cut.	
Brown noncalcareous loamy clay	3–5
Reddish-brown stratified sand and gravel	10
Calcareous clay and talus	A few.
Pinkish calcareous till	8
A few rods farther south.	
Soil and brown loamy clay	3–7
Fresh buff to pinkish till, highly calcareous below 8 feet from the surface of the ground; crystalline pebbles, mostly sound (this resembles till east of Rock River)	20
A few rods still farther south.	
Noncalcareous brownish clay with some pebbles at the bottom	3
Pinkish leached till	2½
Pinkish highly calcareous till with pockets of sand and brown clay	25
In deepest part of the cut near the viaduct.	
Brownish loamy clay	2–3
Buff to brownish till	12–13
Pinkish till	15

Gravel pits near the cemetery in the southeast part of Monroe, in the northwest part of sec. 1 and the northeast part of sec. 2, afford the following composite sections of a deposit of drift shown by wells to be 30 to 35 feet thick:

Section in August Heinzelman's gravel pit.

	Feet.
Black soil.	
Calcareous buff clayey till	4½–6
Cross-bedded gravels	3

Section in Flint's gravel pit.

Brown stoneless noncalcareous clay; absent in places; maximum	3
Buff semistratified leached till	2½
Buff semistratified calcareous till	½–4½
Horizontally bedded sand and fine gravels	4
Cross-bedded sand and gravel	5

Section in J. Taxacher's gravel pit.

Brown loamy clay; absent in places; maximum	2
Very stony till and unassorted morainal gravels with basic bowlders, some schist, and granites up to 1½ feet in diameter largely disintegrated; absent in places; maximum	8
Stratified finer gravel	6
Poorly assorted gravel	8

Section in Abe South's gravel pit.

Buff sandy clayey till; absent in places; maximum	3
Sand and gravel	1–2½
Calcareous sandy clay	⅔–1½
Interbedded sandy clay and fine gravel	3
Stratified sand with cross-bedding, dipping south and southwest	6

In the western part of Clarno Township thick deposits of drift remain which perhaps belong with the terminal moraine. In the SW. ¼ sec. 7, where there has been a slight stream diversion and a newly made rock cut, a well penetrated 40 feet of drift. Several wells in the southern part of sec. 18, in the north and west parts of sec. 19, Clarno Township, and in the SE. ¼ sec. 24, Cadiz Township, penetrated thicknesses of 40 to 85 feet of drift. The digging of the cellar at Mr. Whitehead's house just west of the Honey Creek bridge in sec. 19 disclosed only 5 feet of drift, but 60 rods farther west a well penetrated 80 feet of drift without reaching limestone. These conditions indicate the presence of drift completely blocking the preglacial valley of Honey Creek. In sec. 17 this valley is broad and open, but at the southeast corner of sec. 18 the stream is turned to one side by this dam, and at the bridge it cuts through a narrow ridge of limestone. At two other places in sec. 19 the stream has been forced by the accumulation of drift to cut through spurs of rock before it gets back to the unobstructed valley. Otto Prieve gave the following as his remembrance of the character of the material penetrated in digging a well some 20 years before in the NW. ¼ NE. ¼ sec. 19, Clarno Township:

Log of well at Bert Cox's, sec. 19, Clarno Township.

	Feet.
Drift	20–30
Black muck	10
Yellow clay and muck mixed.	

Cadiz Township (*T. 1 N., R. 6 E.*).—Near the middle of sec. 34 Honey Creek valley is again blocked, forcing the stream to make a new rock cut at the bridge near the old mill, north of which on the divide thicknesses of 28 to 40 feet of drift are penetrated by wells. A mature erosion topography, however, obscures the moraine.

Above a point 2 miles south of Browntown the Pecatonica meanders through a flat-bottomed valley one-half to 1 mile in width. At the north line of sec. 27 this valley is completely blocked by a broad ridge of drift a square mile in extent. The ridge has been partly eroded but still rises 60 feet above the valley floor to the north. Several wells on this ridge penetrated 75 to 180 feet of drift, mostly blue clay, without reaching rock. No drift other than a few scattered crystalline pebbles has been found farther north in this valley, so this drift ridge is clearly part of the terminal moraine. Unable to penetrate it, the river turns aside and for a mile traverses a gorge barely wide enough for the stream and the railway, and then returns to the open valley south of the ridge. Two miles farther south, at the State line, the valley is similarly blocked and the stream similarly cuts through the limestone ridge at Martintown and occupies a tributary valley until the obstruction is passed. The wells on the ridge west of the village penetrate 20 to 80 feet of drift without reaching rock. One well at Ditman's encountered wood beneath 60 to 70 feet of blue clay; the water was not fit for use.

The lake held in the Pecatonica Valley when the ice front stood 2 miles south of Browntown must have been very large (Pl. III, in pocket), as the lowest place on the rim of the basin outside the limit of glaciation is not far from 1,000 feet above sea level. This place is in the vicinity of Warren, Ill., where the waters must have overflowed along the glacial border to the head of Apple River and discharged thence to the Mississippi. No exposure of the silts was seen, but these probably underlie the broad, flat bottoms which border the several tributaries well up toward their sources.

A gully in the slope west of the bridge at the northwest margin of the drift fill (SE. ¼ sec. 17) exposes about 3 feet of buff to brownish stoneless clay, grading downward into 15 feet of fresh pinkish clayey till that carries many fresh-looking pebbles of Niagara dolomite. The upper clay is noncalcareous, and the till is leached to a depth of 5 feet from the surface of the ground, below which it is highly calcareous. This till closely resembles that seen east of Rock River in Walworth County.

Scattered crystalline pebbles and bowlders, a few quartzite pebbles, and other patches of thin till were seen west of the river in the southwestern part of the township.

Wayne Township (*T. 1 N., R. 5 E.*).—From the drift dam in the Pecatonica Valley the ice margin extended southwestward across the southeastern part of Wayne Township. In most places the only apparent evidence of glaciation is the occurrence of scattered crystalline pebbles, pebbles of Niagara dolomite, a few fragments of pink sandstone, and a little thin till. In the northern part of sec. 33, however, the valley of Spafford Brook is blocked by a dam of drift 30 feet high, at the west end of which the stream has cut a narrow outlet through the drift and limestone. This is the most westerly distinct deposit of glacial drift noted, though near the State line, a mile west of Spafford Brook, one crystalline pebble and two small bowlders were noted. Leverett informs the writer that he observed a 3-foot bowlder near the southeast corner of sec. 31, or one-half mile west of this point; so it is probable that the ice front crossed the State line into Illinois within 1½ miles west of this stream. The writer's investigations were not carried farther west.

VALLEY TRAINS.

In connection with their admirable description of the border phenomena of the older drift of this part of Wisconsin, Chamberlin and Salisbury [1] note the absence of trains of valley drift leading away from the attenuated border of this older drift and contrast this fact with the notable development of these trains along the border of the later drift. This relation is perhaps more notable farther southwest, in Illinois, where the drainage lines lead more directly away from or along the drift border. In this part of Wisconsin, however, the main drainage lines lead toward the drift border, so that when the ice sheet was present the upper parts of the tributary valleys of Sugar and Pecatonica rivers must have been flooded by ponded waters whose level could not have been much below the levels of the foot of adjacent parts of the ice front. Such bordering bodies of standing water would not favor the development of valley trains leading away from the ice front. They would favor the silting up of the bottoms of these valleys, and this appears to have taken place extensively.

GROUND MORAINE.

In the area between the morainic border belt, the State line on the south, and the Sugar River valley on the east, the topography is of a mature erosion type everywhere except in the silted-up bottoms of the valleys and in a few small tracts to be noted. A comparison of *A* and *B*, Plate XVII (p. 141), showing respectively driftless upland slopes on the Galena dolomite and Trenton northwest of Monroe and similar limestone slopes thinly covered with glacial drift northeast of Monroe, in Mount Pleasant and Sylvester townships, indicates their similarity in degree of maturity. In a few places the topography within the limit of the drift even more closely simulates that of the Driftless Area—for example, in sec. 29, Mount Pleasant Township, where the removal of the limestone caps from buttelike ridges has permitted the development by weathering of towers in the friable St. Peter sandstone (Pl. XI, *B*, p. 81) similar to the rock pillar near Footville (Pl. XVI, *A*, p. 140). All these have been clearly formed since the disappearance of the ice sheet, for otherwise they would not have been preserved.

Generally throughout this area the drift is very thin. Roads and gullies on the slopes and uplands show, over considerable tracts, only a thin layer of pebbles, mostly crystalline, and rarely a few quartzites with the residual cherts on the surface of the limestone beneath the

[1] Chamberlin, T. C., and Salisbury, R. D., Preliminary paper on the Driftless Area of the upper Mississippi Valley: U. S. Geol. Survey Sixth Ann. Rept., pp. 270-271, 1885.

buff to brownish loamy clay soil. Scattered bowlders also occur on the surface but nowhere abundantly. Here and there in favorable situations a thin bed of till or a deposit of glacial gravel is seen. The amount of surface wash accomplished by a single downpour of rain in this region indicates that a considerable thickness of drift may have been stripped off the slopes and crests and deposited as alluvial silts in the valley bottoms. Wherever a sufficient thickness of till remains to show its original character, it is found to have suffered but little alteration. The upper 2 or 3 feet below the loamy clayey soil is leached and oxidized to a buff or brownish tint, but the material below this depth is highly calcareous and usually has the pinkish tint so frequently seen eastward to Walworth County. Both crystalline and limestone pebbles are usually sound, clean, and fresh looking. Several cuts on the Illinois Central Railroad between those near Monroe (p. 147) and the State line expose thicknesses of 3 to 15 feet of this till overlying the limestone. In one cut in the NE. ¼ sec. 22 a finely polished and striated block of Niagara dolomite 1 by 1½ by 2 feet was noted, which must have been transported from some place at least 50 to 60 miles to the eastward.

At a few places inside the border belt there are considerable thicknesses of drift, and there is also evidence that the preglacial valleys were not completely filled with drift. About a mile east of Oakley a preglacial tributary valley is blocked by a drift dam on which a well was said to have gone down 141 feet without reaching rock. The postglacial stream shifted a little to one side and cut into the drift to a depth of 50 to 60 feet. The crest of this drift dam lies 120 feet below the crest of the divide a mile to the south, making it evident that the valley was not nearly filled with drift.

In Decatur Township preglacial erosion had developed in the sandstone a broad basin surrounded only with narrow ridges of sandstone thinly capped with Trenton limestone. Here the small amount of erosion since the deposition of the drift is remarkable. Wells show the presence of 25 to 175 feet of drift, an undulating drift topography with some kames is seen, and the diversion of the drainage through the new valley of Jordan Creek has left several square miles of drift topography almost untouched by erosion, though the higher parts rise 80 feet above Sugar River. Jordan Creek has cut a little gorge about 80 feet in depth through the sandstone ridge at one side of the inclosed basin. Taken alone, the topography would indicate a drift sheet entirely different from that in Spring Grove Township to the south. (See Pl. XV, *C*, p. 138.)

In the S. ½ sec. 2, T. 2 N., R. 8 E. (Sylvester Township), a valley is blocked by a drift ridge causing slight stream diversion and the cutting of a new channel in rock, and in secs. 2, 11, and 13 there are accumulations of glacial gravel showing, in secs. 11 and 13, the sag and swell topography of a terminal moraine. In the NW. ¼ sec. 14 there is some indication of a tributary valley filled with drift. Some morainal deposits occur west of Sugar River in the southern part of T. 3 N., R. 9 E. (Albany Township).

MODIFICATION OF THE DRIFT.

Although the superficial modification of the drift west of Sugar River by weathering and erosion, as shown in the slopes and crests, is striking, yet from the numerous drift dams blocking the unfilled valleys and causing the recent stream diversion it is evident that this apparent maturity is due primarily to the deep and thorough dissection of the area prior to the ice invasion. With the exception of these slight diversions the drainage follows preglacial lines, having had to work in valleys which were but partly filled and on slopes which were but thinly mantled with drift. Though the erosion of the drift on slopes of so high gradient has necessarily been considerable and has greatly exceeded that accomplished on the drift of the Wisconsin stage, it does not appear to be comparable to that which drift of Kansan age has suffered. Neither is the degree of weathering and decomposition so great as on the oldest Pleistocene drift sheets. The fresh and unleached character of the till beneath the shallow weathered zone has been noted. Tests at 30 or 40 different exposures show the till to be leached of calcium carbonate to depths of 1 to 7 feet from the surface, with an average depth of 4 feet, beneath which it was generally highly calcareous. These depths include the surficial coating of buff to brownish noncalcareous stoneless loamy clay, which is generally present in thicknesses varying from a few inches to 5 feet or more. The leached top of the till is usually oxidized to buff or brownish, but beneath this there is little or no evidence of alteration and the till is loose and unconsolidated. Limestone and crystalline pebbles, especially the basic crystallines, though considerably disintegrated at a few of the exposures, are generally fresh looking, clean, and sound, and the fragments of Niagara dolomite below this superficial zone show little more alteration than those in the Wisconsin sheets.

LITHOLOGIC COMPOSITION.

Rough analyses of the lithologic composition of the drift of this tract were made at 31 different exposures scattered through 11 different townships. Two of these exposures were just east of Sugar River at Paoli. As in the tracts farther east these were made by counting out one hundred to several hundred pebbles taken indiscriminately from the drift at each place and assorting them according to their lithologic character. The averages resulting from this examination are presented in the table below.

Average percentage of pebbles of different lithologic composition present in pre-Wisconsin drift west of Sugar River, Wis.

	Per cent.
Niagara dolomite	11.3
Galena dolomite and Trenton limestone; Lower Magnesian limestone	55.51
Chert, mostly from local limestone	14.7
St. Peter sandstone	4.4
Huronian quartzite	.55
Crystalline rock	8.14
Doubtful, limestone, shale, etc.	5.26
	99.86
Foreign material	8.14

Comparison of this table with those on pages 139 and 143, which give the composition of the pre-Wisconsin drift east of Sugar and Rock rivers, shows the remarkably uniform composition of this drift sheet. Pebbles of Niagara dolomite were noted in all but 3 of the 31 analyses in this western tract, though generally in smaller percentage (average, 11.3 per cent) than farther east, as would be expected on account of the greater distance from the source of the material. With this falling off there is an increase in the percentage of Galena, Trenton, and Lower Magnesian pebbles, which have not in most cases been distinguished from each other. There is also a larger amount of chert as a consequence of the greater extent of the area traversed by the ice, from which this preglacial residuum of the limestones was to be obtained. Crystalline erratics are present in all analyses, ranging in amount from 0.5 to 20.5 per cent, with an average of 8.14 per cent.

Pink and purple quartzites are present in 13 of the analyses; they are, however, rare, their average being but 0.55 per cent. Fifty or sixty such pebbles were noted scattered over the tract under discussion as far west as the extreme west margin of the drift, except in Wayne Township, where none was found. The largest were 6 by 8 inches in diameter. The average percentage present at the places where estimates were made was about the same as that at 30 places farther east between Sugar and Rock rivers, where similar analyses were made. Many of the pebbles resemble quite closely, so far as can be determined with the hand magnifier, rock from the quartzite ledges in southern Dodge and northern Jefferson counties. Their derivation and distribution are discussed on pages 163–166.

THICKNESS OF THE DRIFT.

The estimated average thickness of pre-Wisconsin drift in the three tracts between the Johnstown terminal moraine, the border of the Driftless Area, and the State line, based on a large mass of data, is 45 feet.

AGE OF THE PRE-WISCONSIN DRIFT.

The pre-Wisconsin drift in the three tracts in southern Wisconsin—that east of Rock River, that between Rock and Sugar rivers, and that extending west from Sugar River to the limit of glaciation—is practically identical in lithologic composition and in degree of weathering. Its greatest differences lie in the amount of erosion, which is apparently progressively greater from east to west. The difference in this respect is such as to afford ground for legitimate difference of opinion as to its relative age in the several tracts. But, though this difference is plainly evident to the writer, he believes it to be due to differences in the preglacial topography and in the thickness of the drift covering, and does not regard it as clearly indicating a sufficiently great difference in age to warrant the assignment of the drift of the several tracts to successive stages of glaciation separated by stages of deglaciation comparable to the main subdivisions of the Pleistocene time scale. After repeated efforts to find some satisfactory ground for the subdivision of the drift exposed at the surface into two or more distinct sheets of different stages of glaciation, the writer has always come back to the conclusion that any boundary, wherever placed and however plausibly placed, would have on both sides practically the same association of conditions, after due allowance had been made for differences in preglacial conditions and for those of original deposition. Consequently, the difference in age may still be considered an open question. The present opinion of the writer, which has not been reached without some misgivings, is that the drift exposed at the surface in these three tracts is of practically the same age and was deposited at one and the same stage of glaciation, though perhaps at two or more substages, or minor retreats and advances of the ice front, in consequence of which the more easterly tract was more thickly covered and the drumloidal features, which are probably to be correlated the morainal deposits west of Rock River, were more strongly developed. It is also quite possible that part of the tract east of Rock River is underlain by an earlier drift sheet.

Study of the continuation of the drift of these several tracts southward across the State line into the northern counties of Illinois has strengthened the writer in this belief because, although the drift in Illinois is generally similar to that in southern Wisconsin, it exhibits a somewhat different discordance in drainage development and in the amount of its superficial weathering. Study of the conditions of weathering and erosion of the Illinoian drift sheet farther south, as described by Leverett, and conference and correspondence with him in regard to the age of the deposit, has led the writer to the opinion that all the drift seen by him exposed at the surface outside the Wisconsin moraines in southern Wisconsin and northern Illinois, except the later gravel terrace deposits and some older gravel deposits described below (see pp. 168 and 169), is to be referred to the Illinoian stage of glaciation.

It is understood that Chamberlin and Leverett concur in this opinion. In his discussion of the drift of northwestern Illinois, Leverett [1] treated the main deposit of glacial drift between the terminal moraines of the Wisconsin stage and the Driftless Area as probably of Illinoian age, but (following Hershey and Buell) he considered the part of the deposit bordering Rock River and extending west across Pecatonica River in Winnebago County and eastward to the terraces bordering the Wisconsin moraines to have been invaded by the ice of a later invasion, the Iowan, to which he referred a rather thin superficial portion of the drift believed to be distinct from the main underlying drift sheet. After later and more extended studies in other parts of the Mississippi Valley, however, Leverett questioned this interpretation, and after reexamination reached the conclusion that no glacier had invaded these counties during the interval between the melting of the Illinoian ice sheet and the incursion of the glaciers of the Wisconsin stage. Leverett's change of opinion is believed to have taken place independent of and prior to the writer's studies in northern Illinois. Chamberlin seems never to have been fully satisfied of the presence in these counties of a sheet of drift intermediate in age between the Illinoian and Wisconsin deposits.

The writer's studies in these counties of Illinois were directed toward ascertaining whether or not the drift there really included a sheet intermediate in age between the Illinoian and Wisconsin and whether the main deposit, regarded by Leverett as probably of Illinoian age, was the same as that in southern Wisconsin, where it had been examined in detail by the writer. The writer's investigations in Illinois were not intended to clear up all questions concerning the drift of that area and were not sufficiently extended to do so. They were, however, sufficient to convince him that the conditions were, in general, the same as north of the State line and to cause him to conclude, as stated above for the pre-Wisconsin drift of southern Wisconsin, that the uppermost drift in Boone County north of Kishwaukee River, in Winnebago County, eastern Stephenson County, Ogle County, northern Lee County, and northeastern Whiteside County, all in Illinois, was of practically the same age and not of two distinct stages of glaciation, and that the whole, together with that of the tracts north of the State line, was probably deposited at the Illinoian stage of glaciation. It is recognized that there is much the same ground in Illinois as in southern Wisconsin for legitimate differences of opinion on

[1] U. S. Geol. Survey Mon. 38, chaps. 4 and 5, pl. 12, 1899.

this point, so that the matter must still be regarded as open. It is probable that there is underlying this Illinoian drift, at least in places, the remains of a still earlier deposit, of Kansan or pre-Kansan age. Leverett has raised the question [1] as to whether there was not a somewhat greater extension of the early them. In figure 7, however, these tracts are provisionally included in the area of Illinoian drift. On this map minor features, such as kames, eskers, and drumlins are not differentiated. The following description and interpretation of the deposits examined by the writer in these counties of Illinois is presented

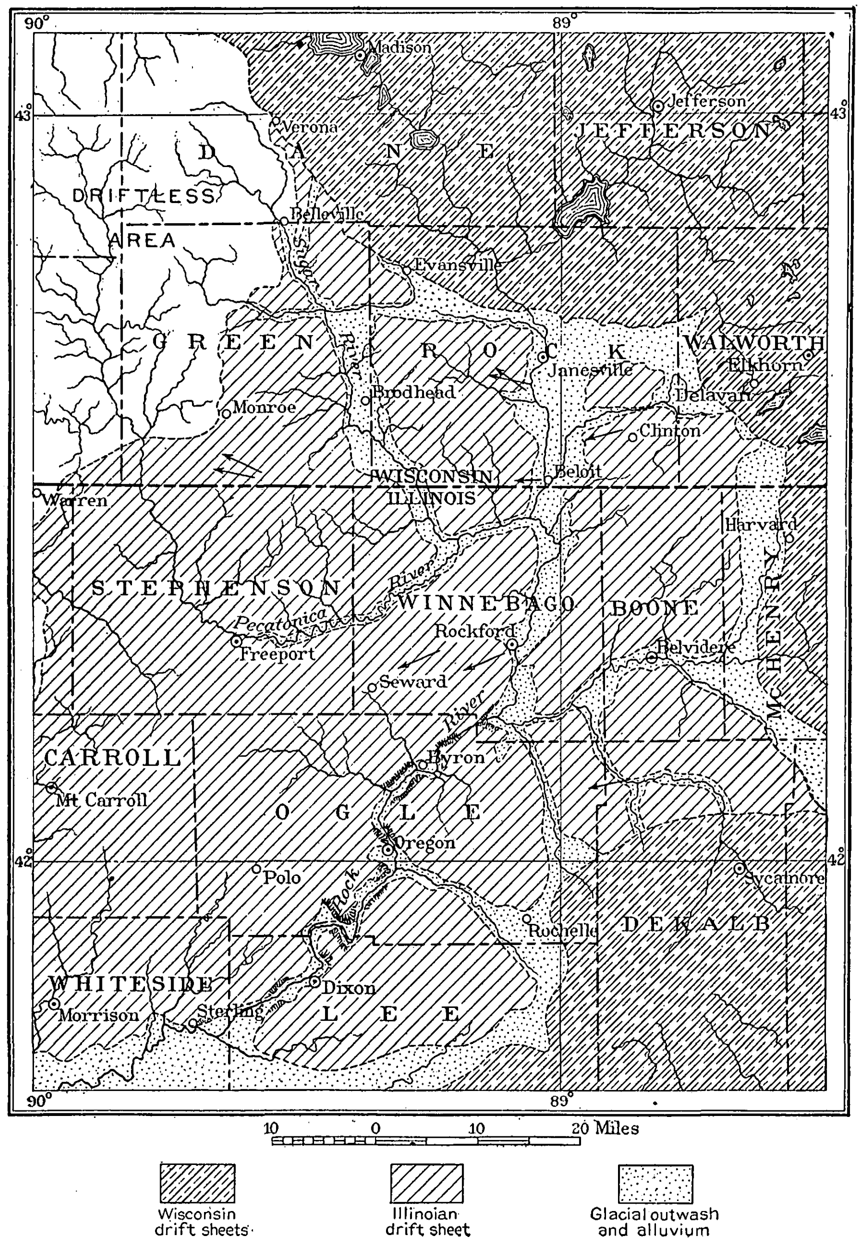


FIGURE 7.—Glacial map of parts of southern Wisconsin and northern Illinois. Boundaries for those parts of Illinois not examined by the writer are taken from Leverett, Frank, The Illinois glacial lobe: U. S. Geol. Survey Mon. 38, pl. 12, 1899.

Wisconsin ice sheet than that shown on the maps in Monograph 38 into the tracts south and east of Dixon and south of Belvidere. Not having examined these tracts, the writer is not prepared to express an opinion concerning as an alternative for that given in Monograpn 38, to which reference should be made for the earlier and more complete discussion of the drift, the drumlins, eskers, and kames, and associated loess and fossiliferous silts.

[1] Personal communication.

ILLINOIAN DRIFT OF NORTHWESTERN ILLINOIS.

DRIFT EAST OF ROCK RIVER.

The topography and drift of the upland east of Rock River in Turtle, Clinton, and Sharon townships, Rock and Walworth counties, Wis., continue southward without change in character in eastern Winnebago and Boone counties, Ill., to the valley of Kishwaukee River. The upland is a gently undulating plain, with some slight undrained sags and low drumloidal swells, scarcely touched by erosion except on the slopes of the preglacial valleys which head in this area. Wells in northern Boone County show 100 feet or more of drift and even in eastern Winnebago thicknesses of 30 to 90 feet are reported, though the usual thickness is much less, especially on the valley slopes. In the western part of Guilford Township the till sheet extends nearly across the preglacial valley of Rock River, having never been removed by erosion. The valley, which at Harlem is 3 miles in width, is reduced to a width of barely one-half mile at Rockford, and in pre-Wisconsin time was entirely blocked by this filling and its waters forced through Kents Creek valley in the western part of the present city. The position of the preglacial valley east of Rockford is indicated by the thickness of drift penetrated by E. A. Kuharske's well in the creek valley in the NE. ¼ sec. 18, T. 44 N., R. 2 E. (Guilford Township), 1¼ miles northeast of the upper bridge at Rockford. This well, starting about 30 feet above the creek and not more than 75 feet above Rock River, penetrated the following deposits:

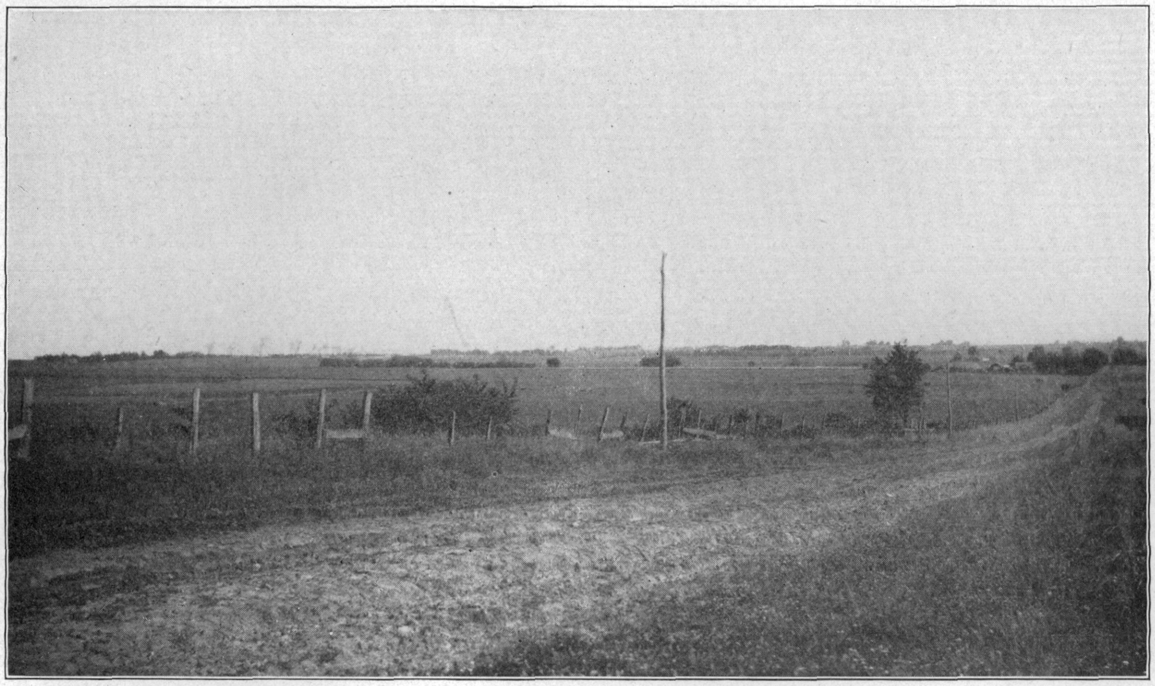
Log of E. A. Kuharske's well, NE. ¼ sec. 18, Guilford Township, Ill.

	Feet.
Blue clay till	90
Sand with a little gravel in streaks and at the bottom	154
	244

From this record it appears either that there was a considerable deposit of sand and gravel in the preglacial valley prior to the advance of the Illinoian ice sheet or that the sand was deposited at the time of this advance and then covered by the till sheet as the ice crossed the valley.

The till mantling the eastern upland is similar in character and composition to that found in Wisconsin. Where seen it is clayey, rather compact but not indurated, pinkish or bluish in its unaltered part, and, if one may judge from the character of the pebbles, contains 70 to 90 per cent of calcareous material, a large part of which is from the Niagara dolomite. This drift has been more or less altered since the time of its deposition by exposure to the weather, which has oxidized its ferruginous constituents and has removed by solution the more soluble constituents, particularly the finer calcareous ingredients. The depth to which this alteration has proceeded varies somewhat from place to place. In the railway cut 2 miles southeast of Roscoe, sec. 2, T. 45 N., R. 2 E. (Harlem Township), the leaching has gone down 10 to 13 feet in the finer material of the matrix but has not removed all the limestone pebbles. The leached part is oxidized to brownish and the unaltered till is light gray. In sec. 36, T. 43 N., R. 1 E. (New Milford Township), 7 miles south of Rockford, in a cut on the Chicago, Milwaukee & Gary Railway, the zone of weathering is 8 to 15 feet in depth, below which the till is highly calcareous and contains a high percentage of Niagara material. The removal of the calcareous rock flour so largely composing the matrix of the till has left the weathered part loose like a bed of gravel upon the unaltered clayey till (Pl. XVIII, *B*), but examination shows this upper part to be not a distinct deposit of water-laid material but a residue due to long-continued leaching. This exposure and the one in sec. 2, T. 45 N., R. 2 E. (Harlem Township), show the greatest known depths of alteration in the area. Evidently at these places but little if any of the weathered drift was removed by surface wash. The known depths of alteration elsewhere east of Rock River vary from 2 to 6 feet and average about 4 feet. Most of the exposures are on slopes where at least a moderate amount of removal of the altered drift by surface wash must surely have occurred. At most exposures, although much of the finer calcareous material has been leached out to the depths indicated, the limestone pebbles have not usually been removed, or if removed from the top part they occur in increasing numbers with etched surfaces lower and lower in the zone of alteration.

A few pebbles of quartzite and some bowlders 1 by 2 by 2 feet in size were observed by the



A. ILLINOIAN UPLAND DRIFT PLAIN OF REMARKABLY LONG, GENTLE UNERODED SLOPE 10 MILES WEST OF ROCKFORD, ILL.

The drift is probably of moderate thickness, overlain by a few feet of loess and underlain by Galena dolomite.

B. ILLINOIAN DRIFT EXPOSED IN CHICAGO, MILWAUKEE & GARY RAILWAY CUT 7 MILES SOUTH OF ROCKFORD, ILL.

The lower part is dense calcareous unmodified boulder clay; the upper 8 feet is gravelly leached and oxidized drift; all limestone pebbles and limestone flour are removed from the latter by solution.

writer on the upland east of Rock River in eastern Winnebago and western Boone counties.

Overlying the weathered surface of the till at many places in the towns of Roscoe, Harlem, and Guilford, in Winnebago County, there is a coating of loess 1 to 6 feet thick. Only where this loess is more than 5 feet in depth is its lower part calcareous, and here it is grayish. Where thinner, it is buff-colored and noncalcareous. The loess lies principally on valley slopes, where it appears to have been deposited after most of the weathering and erosion had been accomplished. On the undissected upland the till is covered by a more compact grayish clay resembling the clay of the matrix of the till below. This clay is stoneless and noncalcareous and is usually 2 to 3 feet thick.

DRIFT WEST OF ROCK RIVER.

TOPOGRAPHY.

Between Rock and Sugar rivers, in the towns of Rockton and Shirland, Winnebago County, conditions are similar to those north of the State line. Coon Creek follows the line of a drift-filled valley of considerable dimensions. Two wells in sec. 9, T. 46 N., R. 1 E. (Rockton Township), show the character of this filling.

Log of D. N. Grant's well, sec. 9, Rockton Township, Ill.

	Feet.
Sandy soil	8
Pebbly blue clay	100
Gravel and sand	20
	128

Log of W. C. Johnson's well, sec. 9, Rockton Township, Ill.

	Feet.
Sandy soil.	
Blue clay	140
St. Peter sandstone	6
	146

About three-fourths mile west of Mr. Grant's well Trenton limestone is exposed in the road marking the west side of the buried valley. Evidently the ancient valley of Coon Creek was never reexcavated after the disappearance of the Illinoian ice sheet. The soil is sandy throughout this tract, and in Shirland Township it forms sand dunes. At one point 6 feet of thoroughly leached till, which looked like a gravel bed, was exposed below the sand. Closer examination, however, showed that it was probably weathered till with pebbles of chert and crystallines and a few of limestone whose surfaces were roughly etched by solution.

West of the broad alluvial plain of Sugar River the sandy soil, as in Wisconsin, is absent, giving place to a heavy stoneless clay, like the clay matrix of the till, neither loose like the sand or loamy like the loess, and like the soil east of Rock River in the upland in Roscoe and Manchester townships. This clay is 2 to 4 feet thick and overlies the brownish leached and oxidized upper part of the till. A large gulley in sec. 35, T. 29 N., R. 10 E. (Laona Township) gives an excellent exposure of the till. The upper 1 to 2 feet is this stoneless brown clay. Beneath this is 1 foot of rusty brown till, thoroughly leached and compacted with indefinite banding as though due to settling or pressure. Through the next 5 feet the clayey till is brown and well leached but looser, with a few rotten or roughly etched limestone pebbles. In the lower part of this portion lime carbonate begins to show and for the remaining 6 feet of the section the clayey till is highly calcareous and contains abundant fresh, smooth limestone pebbles, most of them of Trenton limestone but some of Niagara dolomite. At one point a thickness of 15 feet seems to be entirely leached of its lime carbonate. The slopes in southeastern Laona and northern Durand are generally long and smooth and very little marked by drainage lines.

In preglacial time the upland south of the Pecatonica Valley and west of the Rock River valley in Winnebago, Ogle, Lee, and Whiteside counties, Ill., stood 400 to 500 feet above the bottom of the Rock River valley. Wells in Wisconsin show the present elevation of the rock bottom of this ancient valley to be as low as 450 feet above sea level as far north as Lake Koshkonong. The well at the Malleable Iron Works on the outwash terrace south of the east side of Rockford penetrated sand and gravel for 285 feet, or to about 445 feet above sea level, before reaching the St. Peter sandstone, which here formed the bottom of the ancient valley. Less than one-half mile west of this well limestone is exposed in a quarry on the east bank of the river, and on the west side of the stream it rises in a bluff from the crest of which the surface rises gradually westward to the upland. The upper slopes on the limestone were long and not greatly dissected. Coon Creek and Pecatonica and Sugar rivers flowed in valleys 150 feet or more below the level of their present flood plains.

LITHOLOGIC COMPOSITION.

On this upland the Illinoian ice sheet left a deposit of till of the same character as that in southern Wisconsin and that east of the Rock River valley in Illinois. This till is pinkish or grayish stony clay, and is fairly compact but not indurated—a highly calcareous magnesian limestone till. Estimates made of the pebbles at four places showed the following average composition:

Averages of four estimates of pebbles in the Illinoian till.

	Per cent.
Niagara dolomite	23.37
Galena dolomite and Trenton limestone	57.12
Chert	3.00
Sandstone	1.12
Quartzite	1.50
Crystalline rocks	14.12
Shale, etc	.25

With this till are some esker and moraine gravels of similar lithologic composition. Erosion and slope wash subsequent to the disappearance of the Illinoian ice removed a certain amount of the finer clay of the drift, and this accumulated, in part at least, in the valley bottoms as compact bluish or gray clay. From 3 to 5 feet or more of this clay is exposed in many gully and creek banks beneath a later deposit of black alluvium 1 to 6 feet or more in thickness, which probably represents the wash since the drift became covered with vegetation and the humus soil was developed and possibly is very largely the alluvial wash swept from the cultivated slopes.

About the same varieties of rock are represented among the bowlders on the surface in this part of Illinois as in the adjacent part of Wisconsin. A few bowlders of quartzite, one of them about 1½ by 2 by 3 feet in size, were observed, and quartzite pebbles are plentiful as far south as the line of the Illinois Central Railroad, approximately as shown by Buell.[1] South of the Illinois Central line the writer observed quartzite bowlders much less frequently, though he saw them here and there southward through Ogle County and as far as the line of the Chicago & North Western Railway in northern Lee County.

The writer's studies were not extended westward to the limit of the drift in northwestern Illinois, so that he is unable to state whether or not the quartzite content of the drift continues westward to this limit as it does in southern Wisconsin. Quartzite was seen, however, at one point 45 miles or so south of the State line, which is even farther west than in Wisconsin. In an exposure 6 to 8 miles northwest of Morrison, Ill., in a ravine in the SE. ¼ sec. 11, T. 22 N., R. 4 E. (Ustick Township), Whiteside County, quartzite bowlders were notably numerous, and one measured 1½ by 3 by 4 feet. Here as elsewhere a part of the fragments resemble the rock composing the quartzite ledge of the Waterloo, Wis., region.

The matter of derivation and distribution of the quartzite in the drift south of the State line is considered further in discussing the direction of the ice movement. (See pp. 163–166.)

THICKNESS.

The drainage systems on the drift-covered slopes were developed mostly along preglacial lines, but in a few places where drift dams blocked the old lines small gorges were cut by the diverted drainage. One of these occurs in secs. 25 and 26, Burritt Township, others in secs. 33 and 34, Pecatonica Township (T. 27 N., Rs. 11 and 10, respectively). At these places considerable thicknesses of drift must still remain. In one place a well penetrated 70 feet of gravel, and in other places on the slopes and uplands thicknesses of 25 to 40 feet of drift are reported; similar thicknesses are exposed in some of the railway cuts.

The numerous exposures of the underlying limestones show that the average thickness of the drift sheet is not very great; and, although there are evidences that more or less drift has been removed from the slopes since its deposition, the general character of the topography does not indicate that the amount has been great. The slopes are generally long and smooth and not sharply cut by drainage lines, and there are large, gently undulating, nearly flat or plain tracts, which show no noticeable modification by erosion (Pl. XVIII, *A*), though it is true that a small amount of this might be obscured by the thin deposit of loess which is generally present. The drift overlying the limestone at most of the exposures is less than 10 feet thick, at many it is only 3 to 4 feet, and at not a few it consists of only a thin layer

[1] Buell, I. M., Bowlder trains from the outcrops of the Waterloo quartzite area: Wisconsin Acad. Sci. Trans., vol. 10, pp. 496-500, pl. 15, 1895.

of gravelly drift between the rock and the base of the loess.

ALTERATION.

Generally throughout this tract the upper part of the drift shows the effects of alteration by exposure to the weather during the long time since its deposition. The amount of this alteration is one of the most important reasons for referring its deposition to the Illinoian stage of glaciation. Where the drift is very thin it is little more than a layer of gravel composed of pebbles of less readily soluble rocks such as dense fine-grained crystallines, quartzites, quartz, and chert. Where thicknesses of 2 or 3 feet remain the drift is brown or reddish brown, sandy, and gravelly, with perhaps some noncalcareous clayey matrix but with few limestone pebbles (and those with surfaces roughly etched by solution). Where thicknesses of more than 5 to 6 feet remain the drift below this depth is usually unaltered, highly calcareous, fresh till. The top of the unaltered clayey till is generally marked by an abrupt change in color from bluish, gray, pink, or buff to dark brown or red; the matrix becomes more gritty and less clayey, is largely or quite leached of its lime carbonate; and the limestone pebbles are few and rotted or have roughly etched surfaces. A few inches above, or within about a foot, the limestone pebbles disappear entirely and only sand and pebbles, of the less easily soluble rocks are found, compactly bound together by a little sticky, noncalcareous clay. In this part, which in many places is 2 to 4 feet thick, there is sometimes an indefinite banding as though due to settling or pressure.

The altered drift is in reality the residuum of thorough leaching and rotting of the magnesian limestone till and its thickness is not the full measure of the alteration. If the high percentage of calcareous material still present in the yet unaltered till originally continued to the surface of the deposit, as there is good reason for thinking it did, then the residual layer of insoluble constituents is only about 20 per cent of the thickness subjected to alteration. In other words the 3 to 4 feet of residual till represents the concentration of the insoluble constituents contained in an original thickness of 15 to 20 feet. Even if, for conservatism, the calcareous and other soluble material is considered as comprising two-thirds of the unaltered drift, a thickness of 9 to 12 feet must have been reduced to yield 3 to 4 feet of residuum. This is much greater than the reduction in the Wisconsin drift and indicates much longer exposure.

The following descriptions of exposures of the much altered drift are typical:

Exposure of drift half a mile south of Seward, Ill.

	Feet.
On the slope; a coating of buff, noncalcareous loess; the lower 16 inches of the thickest part is banded but not stratified	2–4½
Dark-red residual till, containing chert, quartzite, and crystalline pebbles but no limestones; not loose but gritty and compact, breaking in little unindurated blocks; rests directly on limestone through most of the exposure	2½–4
In the lower third of the gully's length the limestone drops below the bottom and the red residual till grades downward into light-buff highly calcareous limestone till with abundant fresh clean pebbles of Niagara dolomite.	

The electric-railway cut back of John Eaton's place, sec. 1, T. 26 N., R. 11 E. (Seward Township), 2 miles northwest of Winnebago, gave the following section:

Exposure of drift 2 miles northwest of Winnebago, Ill.

	Feet.
Brown noncalcareous loess; enveloping a buried bowlder	1½–3
Dark-red gritty residual noncalcareous till, from which most of the limestone pebbles have been removed	2–2½
Brownish partly leached till; gradation zone	½
Buff highly calcareous till.	

An estimate of the character of the pebbles from the unaltered till showed the following:

Estimate of pebbles in unaltered till from same exposure.

	Per cent.
Niagara dolomite	32
Galena dolomite and Trenton limestone	56
Crystallines	12

A third exposure, afforded by the bank of a small creek 8 miles west of Sterling, sec. 29, T. 21 N., R. 6 E. (Hopkins Township) Whiteside County, just south of the Chicago & North Western Railway, showed the following:

Exposure of drift 8 miles west of Sterling, Ill.

	Feet.
4. Typical buff calcareous loess standing with vertical or overhanging face, indefinitely banded in the lower part	8–10
3. Brown noncalcareous chert and quartz gravel or residual till	4
2. Compact yellow sand	1–2
1. Dense hard calcareous till, containing dolomite and crystalline pebbles and coal fragments. Upper 3 to 5 feet oxidized buff, grading downward to bluish gray	8

This last section is somewhat ambiguous. The lower dense till (1) more nearly resembles the Kansan till occurring to the west in Iowa than the unaltered Illinoian till seen farther north. If No. 1 is Kansan, No. 3 is probably the residuum of a thoroughly weathered bed of Illinoian till. The deposit, both north and south of the road, looks more like this than it does like a bed of water-laid gravel. If, however, the lower dense till is Illinoian, the drift is different in character from that seen farther north, for it contains a smaller contribution from the dolomites and a larger one from the Maquoketa ("Cincinnati") and Carboniferous shales.

That the lower dense till (1) is probably Illinoian appears from the fact that similar dense gray unaltered till is exposed beneath the loess in a road cut 3 miles to the east and also about 10 miles to the northwest, in the SE. ¼ sec. 18, T. 22 N., R. 5 E. (Clyde Township), Whiteside County.

At the latter place, which is 5 miles north of Morrison, there is evidence that a till which underlies this blue-gray till may be the Kansan drift. In the creek bank, 40 rods north of the road, 15 feet of solid clayey calcareous till, containing pebbles of Niagara dolomite and fragments of coal, is exposed. This is oxidized buff to brown at the top, grading downward in 8 feet to grayish buff and bluish gray. Below this, at the water's edge, is tough, sticky stoneless blue clay. In the barnyard just north of the road the bank exposes 7 feet of similar buff to grayish calcareous till, overlying 2 to 2½ feet of tough stoneless blue laminated silt, underlain in turn by 5 feet of yellow or brownish oxidized clayey till.

This looks as if till (possibly Kansan) had been deposited, had been oxidized (and perhaps eroded), and had then been covered by a deposit of glacial silt, which was in turn buried by the deposition of Illinoian till. In places in the roads near by a gray calcareous clayey till, like the Illinoian, is exposed. Higher up the slope this unaltered till disappears beneath brown leached till, from which the limestone pebbles and other calcareous material have been removed to a depth of at least 2 feet.

Another exposure in the SE. ¼ sec. 11, T. 22 N., R. 4 E. (Ustick Township), about 2½ miles northwest of those last described and about 4½ miles north and 1¾ miles east of Union Grove, is north of the east-west road in a gully tributary to Otter Creek near its head. This shows in generalized section:

Exposure of drift northeast of Union Grove, Ill.

	Feet.
Buff loess (absent in places); maximum	5
Dark-red or brownish-red till, purplish in part, especially at the bottom, with noncalcareous clay matrix, in which the pebbles are of fine-grained greenstone, quartzites, quartz, and chert, with few or none of limestone. Cracks and holes in the till from which limestone pebbles have probably been removed by solution are lined with a dark-brown coat of unctuous clay	4–10
Cherts and rotten limestone fragments	⅔
Fine loesslike buff clay, slightly calcareous	1
A few rods north of the road yellow weathered limestone is exposed in the gulley bottom and with this some dense, sticky, tough white clay. In places the limestone is disintegrated to a yellowish powder or even to a dark-brown residual clay.	

Though few limestone pebbles are contained in the till, there are some large surficially rotted blocks of limestone. There is a remarkably large number of quartzite bowlders (one ½ by 3 by 4 feet in size), most of which have smooth, rounded surfaces. Another constituent of this drift, not previously noted by the writer, is a hard ferruginous conglomerate with pebbles mostly or entirely of yellow chert, of which many pieces were found. This is from some preglacial gravel conglomerate, perhaps from remnants of Cretaceous or Tertiary gravels, such as have been reported from northwestern Illinois, southwestern Wisconsin, and northeastern Iowa. (See p. 101.) The alteration of the drift exposed in the main gully is so marked that at first it appeared to the writer that the till must surely be older than Illinoian, as indeed it may be; but a few rods up, in one of the short tributary gullys, the red residual till was found to grade into buff highly calcareous till, with fresh glaciated limestone pebbles barely 5 feet below the base of the loess. Here the conditions are more like the Illinoian drift. The relations show that a preglacial gulley in the limestone was filled with drift and was then partly eroded. The drift was weathered and the gully was again filled with loess and still later was again partly eroded. The line of the main gully, which is 15 to 20 feet deep, is along that of the earlier ones, which may account for the greater depth and thoroughness of the alteration exposed along it, as compared with that seen in the drift a few rods distant in the tributary gulleys. The Niagara dolomite pebbles seen are of rock such as occurs at Racine, Wis., an indication that the drift came from the east.

RELATIONS OF WEATHERING AND SURFACE WASH.

From the above descriptions it appears that the surficial alteration of the drift both east and west of the Rock River valley indicates the lapse of considerable time, geologically speaking, since the drift was deposited, and this despite the apparent slightness of the erosion on the slopes and upland south of Pecatonica River.

Throughout this area, and in many places in the immediate vicinity of much weathered residual till, other exposures of this same till show very little alteration. Often no residual layer is found and even the matrix of the till is highly calcareous nearly or quite to the base of the overlying loess or loam. Moreover, there are numerous knolls and ridges of calcareous till, or of limestone gravel, some of them eskers rising 5 to 25 feet above the surrounding plain surface. The drift of these knolls and ridges is generally fresh looking and but little if any leached or oxidized. The relations northwest and west of Rockford are such that when first seen by the writer it seemed to him that a later ice sheet must have overridden the Illinoian till sheet and have left thereon a scattered deposit of fresh drift. Careful examination, however, showed that most of these exposures of little weathered drift were on slopes where the weathered surficial part might have been removed by slope wash. At many places there was little or no indication in the topography that more erosion had occurred than in adjacent situations where the residual till layer was still preserved. That such removal had taken place, however, was clearly evident in very many places where the calcareous, little-altered drift was found disappearing beneath a layer of brown or red residual till higher up the slope. Nowhere was fresh unaltered drift found overlying the weathered top of the Illinoian till. Even the unaltered drift composing the knolls and ridges showed no evidence other than the freshness which might be taken to indicate their later origin. In these cases it seems that, even if the weathered superficial part has not been removed by erosion, the configuration and structure of the elevations may explain their lack of weathering.

In the first place, the rounded surfaces of knolls and ridges rising above the plain shed most of the water falling on them much more readily than do the surrounding plain tracts, especially where the latter have long, gentle slopes, such as characterize the area in question. The gravel of the knolls is particularly loose and open, so that such of the meteoric water as penetrates percolates through and out of the gravel very readily has but a comparatively small contact with the surface of the calcareous particles or pebbles. This is true not only because of the large interspaces allowing rapid passage of water but also because the total amount of surface exposed by the pebbles is far less than that where the material is finely comminuted, as in the rock flour matrix of the till. The result is that even though the waters percolating slowly downward may have relatively large solvent action on the calcareous till of the plain and may remove the finer calcareous particles and even the limestone pebbles to considerable depths, they may fail to alter drift of the same age on the knolls and ridges except by solution of a small amount of the surficial parts of the limestone pebbles in the upper part of the elevation and by cementation of the gravel in the lower parts by deposition of the lime carbonate carried down from above. In considering the relative amounts of alteration of two drift sheets due to weathering one must compare clayey till with clayey till, sandy till with sandy till, and sand and gravel deposits with like deposits. Further than this, note should also be taken of the general surface configuration, the relations to drainage lines, and the heights and gradients of slopes.

In studying the evidences of age of the drift considerable differences have been found in different parts of what seem to the writer to be one and the same sheet. Comparison of the topography east and west of Rock River in southern Wisconsin with that in this part of Illinois might readily cause confusion if topography alone was considered. West of Rock River in Wisconsin the topography apparently becomes more mature and more closely resembles that of the Driftless Area as the limit of the drift is approached from the east. Little if any of the upland plain remains, practically the whole area being reduced to slopes, which have usually fairly high gradients and which are scored at intervals of about 10 to 20 rods with drainage lines, many of which notch the crest lines of the divides. This is in marked contrast with the extensive gently undulating upland tracts and long smooth slopes in the area west of Rock River and south of Pecatonica River in Illinois and east of Rock River in both Illinois and Wisconsin. Nevertheless, the drainage system in the Wisconsin area west of Rock River is not nearly so mature as might be thought at first sight of the scored slopes and narrow notched upland crests. Numerous drift dams in the valleys have caused the diversion of the drainage and the cutting of narrow rock gorges. The crests of these dams are well below the upland levels, and the basins above them have clearly not been excavated since the disappearance of the ice. It follows that the valleys never were filled with drift and that their present relief of 200 to 300 feet is due not to postglacial erosion but to the larger features of the preglacial topography, and that the streams for the most part follow preglacial courses with but local diversions due to the drift. Although there are in many places thick deposits of drift in the valleys and even in some places on the upland (as near Monroe, Wis.), the slopes of the mature preglacial erosion topography in general were rather thinly mantled and the surface gradients as left by the ice were rather high. Where this was the case, conditions were favorable to erosion, and a good deal was accomplished. Such conditions of drainage were more favorable to removal of the upper part of the drift than they were to slow downward percolation of the waters and thorough leaching and oxidation such as reduced the upper part of the drift on the upland tracts west of Rock River in Illinois to the residual condition. The condition of good drainage—that is, ready run-off of the waters—seems not to favor thorough leaching and oxidation as much as do low gradient and slow percolation.

The conditions found to-day in the several parts of the drift sheet in question are the resultants of the relative rates of leaching and oxidation as compared with the rates of surface wash in those particular places. Where conditions favored alteration by weathering most and surface wash least the upper part of the drift has been reduced to the condition of residual till. Where the conditions were reversed the drift is fresh or little altered nearly or quite to the surface; this is the result in places throughout the whole Illinoian drift area in northern Illinois and southern Wisconsin, particularly where the rather abrupt marginal slopes dropping down from the Illinoian upland to the valleys are considerably dissected by erosion. Where the rate of surface wash lagged somewhat behind the rate of alteration by weathering the clayey matrix of the till is found to be fairly well leached of lime carbonate to depths of 4 to 6 feet and the color of the leached zone is changed by oxidation from pinkish, bluish, or gray to buff or brownish, but the limestone pebbles have only their surfaces etched or are only partly removed by solution. This is the condition most generally observed where a sufficient thickness of the till is exposed throughout the whole area of the Illinoian drift examined by the writer southward into Lee and Whiteside counties, Ill., excepting only on the nearly flat or gently undulating upland tracts.

CONCLUSIONS.

After consideration of all factors in reference to the pre-Wisconsin drift the writer is convinced that the conditions were, in general, the same in the tracts north and south of the State line, and he is led to the conclusion already stated (p. 152) that the uppermost drift outside the moraines of the Wisconsin stage in southern Wisconsin and northern Illinois (at least in that part of it examined by himself—Boone County, north of Kishwaukee River; Winnebago County; eastern Stephenson County; Ogle County; northern Lee County; and northeastern Whiteside County) is of practically the same age throughout instead of representing two or more distinct stages of glaciation separated by stages of deglaciation, and that the whole was probably deposited at the Illinoian stage of glaciation. He admits, however, that there is legitmate ground for difference of opinion in regard to this matter and that the question of age is not to be considered as positively settled.

DIRECTION OF THE ICE MOVEMENT.

PROGRESS OF INVESTIGATIONS.

When Chamberlin first studied the tract west of Rock River in southern Wisconsin he observed that not only were quartzite bowlders scattered in abundance along the lines of the later glacial flow from the quartzite ledges in the region of Waterloo to the terminal moraine but also that pebbles and bowlders of similar quartzite were scattered, though much less abundantly, over the drift outside the moraine west of Rock River southward to the State line.[1] As no striæ had then been observed outside the moraine (except immediately west of Rock River at Beloit, where Buell had found striæ trending due west) these quartzite pebbles and bowlders were very naturally regarded as derived from the Waterloo ledges and as being in themselves clear evidence that the Green Bay Glacier continued its southerly advance well down into Illinois. Chamberlin stated that the material of the drift, the surface contours, and the striation observed by Buell furnished abundant evidence that the westerly movement of the Lake Michigan Glacier extended to the west side of Rock River and that the line of junction of the two glaciers was west of that stream.

By June, 1882, when Chamberlin submitted for publication volume 1 of the Geology of Wisconsin, the last of the set of four volumes prepared under his direction, doubt had arisen in his mind as to the reliability of the quartzite pebbles and bowlders west of Rock River as indicating a southerly movement of the Green Bay Glacier extending into northern Illinois. The drift west of Rock River had been found to show the same evidence of easterly derivation as that east of this stream, and it was thought the quartzites might have been brought from more distant sources to the northeast. In consequence of this the hypothetical map of Wisconsin during the "first glacial epoch"[2] was so drawn as to indicate the movement of the Lake Michigan Glacier as southwesterly across the extra-morainal tracts here under discussion, though the character of the drift and direction of the ice movement in the particular tracts was not discussed. About this same time Chamberlin's preliminary paper[3] on the terminal moraine of the "second glacial epoch" appeared, in which he showed, more elaborately than had previously been attempted, the distribution of the great terminal moraine in the several States and its relation to the drift outside the moraines. On the map of the "Green Bay loop of the terminal moraine of the second glacial epoch" in that report[4] the only indication of direction of flow of the earlier ice sheet in southern Wisconsin is an arrow pointing due west near Beloit. Like the preceding one, this report did not discuss specifically the drift outside the moraine in Wisconsin.

So also on Plate II of the atlas accompanying the Geology of Wisconsin, dated 1881, a westward-trending arrow on the map near Beloit is the only indication of direction of the movement of the ice of the earlier epoch or stage.

A diagrammatic map of drift currents adjacent to the Driftless Area, published in 1885 by Chamberlin and Salisbury,[5] indicates the general, and in part hypothetical, direction of ice flow in southern Wisconsin and northern Illinois as curving from southwesterly to westerly and extending clear across to the border of the Driftless Area, practically as shown on Plate IV (in pocket) of the present paper.

An arrow indicating striæ at Beloit but apparently not accurately oriented is the only index of the direction of movement of the earlier ice in southern Wisconsin shown on Chamberlin's map of the glacial striæ of the eastern United States issued in 1888.[6]

The drumlins east of Rock River, first observed by Buell, mapped on the Delavan and Shopiere topographic sheets in 1891 by V. H. Manning, jr., and printed in 1893, have approximately the same trend (S. 75° W.) as striæ observed by Buell[7] on the bottom of a roadside gully near the west line of the town of Clinton.

Leverett[8] quotes observations of glacial striæ made by Buell at several points outside

[1] Chamberlin, T. C., Geology of Wisconsin, vol. 2, p. 202, fig. 3, and pl. 7, 1877; also, On the extent and significance of the Wisconsin kettle moraine: Wisconsin Acad. Sci. Trans., vol. 4, p. 229, 1878; also, Le Kettle moraine et les mouvements glaciaires qui lui ont donné naissance: Cong. géol. internat. Compte rendu sess. 1878, p. 265, 1880.

[2] Geology of Wisconsin, vol. 1, pl. 9, 1883.

[3] U. S. Geol. Survey Third Ann. Rept., pp. 291-402, 1883.

[4] Idem, pl. 29.

[5] Chamberlin, T. C., and Salisbury, R. D., Preliminary paper on the Driftless Area of the upper Mississippi Valley: U. S. Geol. Survey Sixth Ann. Rept., pp. 192-322, 1885.

[6] The rock scorings of the great ice invasions: U. S. Geol. Survey Seventh Ann. Rept., pl. 8, 1888.

[7] Buell, I. M., Bowlder trains from the outcrops of the Waterloo quartzite area: Wisconsin Acad. Sci. Trans., vol. 10, p. 494, 1895.

[8] U. S. Geol. Survey Mon. 38, p. 88, 1899.

the terminal moraine in Winnebago and Lee counties, Ill., as follows:

Striæ in Winnebago and Lee counties, Ill., observed by I. M. Buell.

	Direction.
Near Winnebago, Ill., at quarry in sec. 6, T. 26, R. 11 E.	S. 75° W.
Bluff of Kents Creek near Rockford, Ill., two exposures, secs. 28 and 29, T. 44, R. 1 E.	S. 75° W.
Cutting on Chicago, Milwaukee & St. Paul Railway west of Fielding, Ill.	S. 65° W.
Cutting on Chicago, Milwaukee & St. Paul Railway east of Fielding, Ill.	S. 75° W.

In September, 1901, the writer observed markings on an exposure of Trenton limestone 3 miles southwest of Janesville, NE. ¼ sec. 16, T. 2 N., R. 12 E. (Rock Township), that showed the direction of movement to have been 10° to 28° north of west, or S. 100° to 118° W. At this place diversion of the creek to a new course had removed the gravels from a portion of the rock, exposing a beautifully glaciated surface. (See Pl. XXI, *A*. p. 204.) The rather soft limestone contains small hard chert nodules which resisted the glacial planing and were left protruding a fraction of an inch above the surrounding smoothed surface. In the lee of each of these projecting nodules a little half cone of limestone, with the nodule forming its base, was left tapering away in the direction of the ice movement. These are excellent examples of phenomena described by Chamberlin as "knobs and trails."[1] The tail of one nodule, 1¼ inches in width, could be distinguished for 15 inches. Three and one-half inches from the base this cone was broken and cut across by a rather coarse striation bearing N. 68° E. or S. 72° W. No other striation of similar trend was found on the surface. The absence of others and the character of the scratch itself raised a question as to its being of glacial origin. Instead of being clean-cut like those trending northwestward it was coarsely bruised and became fainter toward the northeast as if due to the movement of a bowlder, possibly frozen in ice, along the the creek bed, to which it is nearly parallel. It seemed to the writer that the coarse northeast-southwest scratch was clearly developed subsequent to the formation of the cones and that if it were formed by a southwesterly moving glacier the other cones and other parts of the exposed glaciated surface could not have failed to show similar effects.

The writer's observations on the character and lithologic composition of the pre-Wisconsin drift are entirely in harmony with the hypothesis that the movement of the glacier was westerly clear across to the border of the Driftless Area.

In 1907 the writer observed at two points in southern Green County excellent and plainly marked striæ confirmatory of the belief that the pre-Wisconsin ice advance continued westward, shifting to somewhat north of west as it closed about the southeast side of the Driftless Area. Near the middle of the N. ½ sec. 32, T. 1 N., R. 8 E., about 40 rods north of Fairfield Evangelical Church, 7 miles southeast of Monroe, a well-glaciated ledge was observed in the gully beside the road, bearing striæ N. 63° to 75° W. (or S. 105° to 117° W.). Here the ice was ascending a gentle slope. One and one-half miles northeast of this, in the NE. ¼ SE. ¼ sec. 28, a ledge in the creek bed in the bottom of the valley showed striæ bearing N. 35° to 60° W. (S. 120° to 145° W.), or about parallel to the valley down which the ice was moving. Taken altogether, therefore, there is good evidence that the general direction of the Illinoian ice advance was westerly (more exactly, S. 75° W. to S. 145° W.) across the tracts under discussion to the border of the Driftless Area.

GLACIAL STRIÆ WITHIN LIMITS OF LATE WISCONSIN GLACIATION BUT POSSIBLY OF EARLIER ORIGIN.

Certain striæ observed within the moraines of the Green Bay Glacier of the Wisconsin stage have a more southwesterly trend than those of the later ice movement at the same localities, and it is thought possible that they may be the work of the Illinoian ice sheet, which very probably traversed the same area in a direction varying from southwesterly to westerly. They may, however, have been the work of an intermediate advance, or they may have been due to a local deflection of the last ice movement, for striæ trending southeast as well as southwest have been found in some places, even on the same rock surface.

[1] Chamberlin, T. C., U. S. Geol. Survey Seventh Ann. Rept., pp. 244-245, 1888.

Glacial striæ possibly formed by the Illinoian ice sheet within the moraines of the Green Bay Glacier.

Location.	T. N.	R. E.	Sec.	Striæ, possibly of the pre-Wisconsin Glacier.	Direction of movement in late Wisconsin glacier shown by striæ or by trend of nearest drumlins.
DANE COUNTY.					
Burke station, on Lower Magnesian limestone hill southeast of.	8	10	26, NE. ¼	S. 65°–72° W. S. 108° W.	S. 30°–40° W.
Cooksville (Dunkirk Township, southwest part), on Trenton limestone near.[a]	5	11		S. 50°± W.	S. 25° W.
JEFFERSON COUNTY.					
R. Hooper's quarry, Milford Township, on Trenton limestone.	7	14	6, SW. ¼	S. 42°–46° W.	S. 12° W.
Crawfish River, in road cuts near[a]	7	14	6, SW. ¼	S. 60° W	S. 10°–30° W.
Aztalan Township, in railroad cut on Trenton limestone.	7	14	20, SW. ¼	S. 40°–44° W.	S. 20°–30° W.
Aztalan Township, at quarry near river bank on Trenton limestone.	7	14	20, SE. ¼	S. 35°–45° W.	S. 20°–30° W.
Sumner, in bottom of D. Pierce's cellar, 1 mile northwest of, on Trenton limestone.	5	13	18, NE. ¼	S. 49°–64° W.	S. 15° W.
ROCK COUNTY.					
Lima Township[b]	4	14	3, NE. ¼	S. 50° W.	Due south.
Milton, in wells and cellar bottoms near[a]	4	13		S. 50°± W.	S. 10°–20° W.
Harmony Township, in D. Smith's cellar	3	13	1 or 2	S. 110°–117° W.	S. 20°–27° W.

[a] Buell, I. M., Bowlder trains from the outcrops of the Waterloo quartzite area: Wisconsin Acad. Sci. Trans., vol. 10, p. 494, 1895.
[b] Idem. "On a rock surface uncovered in a roadway section across the end of a well-marked drumlin whose axis lies almost upon the meridian line."

SOURCES OF ERRATICS.

DERIVATION FROM THE WATERLOO DISTRICT.

If the quartzite erratics which resemble the rock of the Waterloo ledges really were derived therefrom, they may possibly have been transported by an earlier southward-moving glacier whose invasion of the area is not otherwise indicated.

Chamberlin has suggested transportation of the quartzites southward from the ledges by drainage along the border of the westward-moving Illinoian ice sheet in or on floating masses of ice. This might perhaps have occurred at certain stages during both the advance and the retreat of the ice front, many of the pebbles and the bowlders brought first being incorporated in the drift and those brought as the ice melted being left on its surface. It has occurred to the writer that, as the Waterloo quartzite ledges were probably surrounded in preglacial time by considerable valleys (Pl. II, in pocket, and p. 116) tributary to the Rock River valley, pebbles and bowlders from the disintegrating conglomerate or frost-riven angular fragments might readily have found their way by gravitative action or wash down the sides of the ledges to the streams. Thence, especially if frozen in ice, they might have been moved down the valley season by season and might eventually have reached points as far south as any at which these erratics have been noted. A time when Rock River was flooded by waters escaping as the front of the Illinoian ice sheet approached the ledges and the valley from the east would be particularly favorable to such glacionatant transportation. Some of the quartzite erratics thus strewn along the valley might become incorporated in the advancing Illinoian ice and be scattered thence westward over the area, some even reaching the limit of the advance.

It is to such a westward-moving glacial advance as this that Buell[1] has referred the quartzite pebbles and bowlders scattered sparsely westward from the ledges to the terminal moraine, within the limits of the later

[1] Wisconsin Acad. Sci. Trans., vol. 10, pp. 500–504, pl. 16, 1895.

advance of the Green Bay Glacier of the Wisconsin stage.

One objection to accounting for the presence of quartzites in the pre-Wisconsin drift outside the terminal moraines by stream or combined stream and glacial action is that it does not explain the presence of a small amount of quartzite of the same type on the uplands east of the Rock River valley. It is not apparent how such pebble-bearing waters from the vicinity of the Waterloo ledges could get into preglacial Troy Valley on the east side of the uplands. A large part of the quartzites in the pre-Wisconsin drift, of which hundreds of chips have been collected from the different tracts and examined with a hand glass by the writer, do not resemble any quartzite exposed in the Waterloo ledges, so that much of it must have come either from unexposed ledges in that vicinity or from some other source.

DERIVATION FROM LEDGES NORTH OF LAKE HURON.

Chamberlin has suggested that the quartzite erratics outside the moraines may have come from ledges north of Lake Huron. Although no attempt has been made to identify the numerous varieties of igneous and metamorphic rock comprising most of the pebbles and bowlders scattered over the surface of the pre-Wisconsin drift in such a manner as to be able to trace them to their source, a few erratics are of such striking character as to attract attention. Among these are bowlders of red quartz porphyry, of red porphyry without quartz phenocrysts, and of pale-purple quartzless porphyry. These, especially the bowlders of red quartz porphyry, are most numerous about Sharon, Wis., but they have also been noted at numerous other places. Other erratics are pebbles of blood-red jasper and pieces of conglomerate of white sandstone or quartzite matrix carrying pebbles of bright-red jasper.

Still other interesting erratics are the nuggets of native float copper. Many of these have been collected within the later terminal moraines, and some have been reported from the older drift outside the moraines. In a paper published in 1885 Salisbury [1] mentions the finding of a bowlder of copper of 40 or 50 pounds weight in Walworth County, Wis., near the State line. This was reported by Whittlesey, [2] but as the exact location is not given it is not known whether it came from east or west of the limit of the later drift. Salisbury states also that Chamberlin has records of about 30 specimens from Walworth County, but he does not say whether these were from the earlier or the later drift. He also cites Chamberlin as authority for the statement that a specimen of 114 pounds weight, which was found at Newark, Rock County, Wis., on the older drift, had attached to it fragments of Keweenawan rock. He cites James Shaw [3] as reporting drift copper from the area of the older drift in Stephenson, Winnebago, Boone, Ogle, and Lee counties, Ill.

Retracing in a general northeasterly direction the probable path of the Labradorean ice which traversed the tracts under discussion in southern Wisconsin and northern Illinois, it is found that rock such as comprises these particular erratics occurs in the pre-Cambrian formations of Ontario north of Lake Huron and along the east shore of Lake Superior and on Michipicoten and some other islands. In his report on the geology of Canada published in 1863 Sir W. E. Logan [4] describes and maps in this region several belts of white, gray, and light to red quartzite, and also white quartzite carrying bright-red jasper pebbles.

In a paper on the secondary enlargements of mineral fragments in certain rocks,[5] Irving and Van Hise describe the microscopic characters of specimens of quartzite from the typical Huronian region north of Lake Huron. One of these is a purple vitreous quartzite; others are gray, white, and red. Logan states [6] that in the Huronian country there is scarcely any considerable area wholly destitute of cupriferous veins. Most areas, it is true, do not carry native copper, but its occurrence is reported from several places. Testifying before the Royal Commission on the Mineral Resources of Ontario, E. B. Borrom [7]

[1] Salisbury, R. D., Notes on the dispersion of drift copper: Wisconsin Acad. Sci. Trans., vol. 6, p. 46, 1885.

[2] Smithsonian Contr. Knowledge, vol. 15, p. 11, 1867.

[3] Illinois Geol. Survey, vol. 5, 1873.

[4] Logan, W. E., Canada Geol. Survey Rept. Progress, pp. 57-61, 1863. Map of Huronian rocks between Rivers Batchehwahnung and Mississagui, atlas of maps and sections, 1865.

[5] Irving, R. D., and Van Hise, C. R., On secondary enlargements of mineral fragments in certain rocks: U. S. Geol. Survey Bull. 8, pp. 23-27, 1884.

[6] Logan, W. E., op. cit., p. 60.

[7] Report of the Royal Commission on the Mineral Resources of Ontario and measures for their development, p. 98, Toronto, 1890.

stated that 1,400 pounds of native copper had been taken out at Point Mamainse (on the east shore of Lake Superior, near latitude 47° N.), of which the largest mass weighed 600 pounds. J. S. Williams, testifying concerning the mine on Michipecoten Island, stated [1] that native copper "occurs in masses of 40 to 50 pounds to minute particles of very fine shot and leaf copper." D. W. Butterfield [2] reported the occurrence of some native copper at the Vermilion location in the Sudbury district.

Archibald Blue,[3] director of the Ontario Bureau of Mines, reports that copper is found in various localities on the north shore of Lake Huron and on the east shore of Lake Superior, generally as copper pyrites, but sometimes as native and in sulphurets in amygdaloidal trap, conglomerate, and sandstones, as at Mamainse Peninsula and on Michipecoten Island in Lake Superior and at points along the north shore of the lake. In his second report Blue [4] states that the native copper from Mamainse (on the east shore of Lake Superior) and other points north of Lake Superior is precisely like specimens from the famous Michigan copper mine.

E. M. Burwash [5] refers to the occurrence on Michipicoten Island of a red quartz porphyry, a red quartzless porphyry, and a purplish quartzless porphyry. No detailed description of these rocks is given, but the names call to mind bowlders noted on the pre-Wisconsin and later drifts in southern Wisconsin.

No reference has been found by the present writer to the occurrence in Ontario of a bluish-purplish quartzite, such as is so prominent a constituent in the Waterloo ledges and such as composes many of the quartzite bowlders on the pre-Wisconsin drift. If the quartzites of the Ontario area vary in color within short distances as much as does the rock in the Waterloo region they might include sufficient purplish rock to yield all the purple erratics noted and yet be prevailingly of the colors indicated by Logan throughout their extensive belts of outcrop.

From the citations given above it appears that many of the quartzite erratics on the Illinoian drift may have been derived from formations in Ontario, and that some may, in one way or another, have been transported southward from the ledges at Waterloo, Wis.

If some of the quartzite erratics of the pre-Wisconsin drift of southern Wisconsin and northern Illinois were derived from the pre-Cambrian formations of Ontario one would expect to find a small amount of such erratics scattered through the later drift of the Lake Michigan Glacier and that of the eastern part of the Green Bay Glacier, where there was no opportunity for the introduction of quartzite from the Waterloo ledges. As the ice first traversing the Ontario ledges would have a good opportunity of incorporating fragments loosened by preglacial weathering and frost action, it would be expected that the later ice might not have so good an opportunity and that there would be less quartzite in the later drift. Of 268 analyses made at different places by sorting and counting pebbles in the drift of the Lake Michigan Glacier and of that part of the Green Bay Glacier east of Rock River (where there was no chance of the incorporation of Waterloo quartzite), 77 (28 per cent) contained quartzite pebbles; and the whole 268 samples contained 0.23 per cent of quartzite. The same samples contained 12.4 per cent of crystalline rock derived from the great Laurentian areas of Canada. Of 71 similar analyses of the pre-Wisconsin drift of southern Wisconsin and northern Illinois, principally the former, 26 (36 per cent) contained quartzite, and the 71 samples contained 0.56 per cent. These analyses also contained 10.56 per cent crystallines.

LOCAL SOURCES.

In discussing the relations of the unexposed pre-Cambrian rocks in the area (pp. 70–71) the possibility was pointed out that some of the crystalline bowlders, and particularly some of the quartzites thought to be foreign, might possibly be from local ledges. It was noted, however, that the cover of Paleozoic sediments thickens rapidly eastward and that the probability of such ledges having been exposed to glacial abrasion decreases correspondingly.

In a personal communication to C. W. Hayes in December, 1910, I. M. Buell stated that careful study of a ledge surface uncovered in a quarry near Beloit had revealed fine striæ

[1] Idem, p. 103.
[2] Idem, p. 105.
[3] Blue, Archibald, Ontario Bur. Mines First Rept., p. 175, Ontario, 1892.
[4] Blue, Archibald, Ontario Bur. Mines Second Rept., p. 192, Ontario, 1893.
[5] The geology of Michipicoten Island: Toronto Univ. Studies, Geol. ser., No. 3, pp. 22, 23, 29, 39, 40, 1905.

bearing due south. He says it is apparent from their presence on a surface previously polished and scored by lines of westward movement that the clay mantle, consisting of about 10 feet of almost pebbleless clay, was moved bodily over this smooth surface, scoring it with fine cross lines. However, if there really was a southward movement of glacial ice over the Waterloo quartzite ledges into northern Illinois the present writer is inclined to think it preceded rather than followed the westward movement of the Illinoian ice sheet.

The general course of the Illinoian ice reaching southern Wisconsin and northern Illinois appears probably to have been southwesterly across the Province of Ontario, the adjacent eastern part of the Lake Superior basin, and the northern end of the Huron basin (if they were then lake basins) across the eastern part of the north peninsula of Michigan, perhaps diagonally along what is now the Lake Michigan basin, spreading thence westward across eastern Wisconsin and northern Illinois to the border of the Driftless Area. If the ice was moving transversely to or obliquely across the Green Bay-Lake Winnebago valley, it is doubtful if a Green Bay lobe of the Illinoian ice sheet was developed.

OLDER DRIFT BENEATH DEPOSITS OF THE WISCONSIN STAGE.

DIFFICULTY OF IDENTIFICATION.

At no place in the part of eastern Wisconsin which was subjected to the vigorous glaciation of the Wisconsin stage have soils or vegetal deposits been found between the Wisconsin glacial deposits and those of an earlier stage of glaciation. There is also difficulty in distinguishing the earlier from the later drift where interglacial deposits are lacking. This is due to the comparative rarity of natural or artificial sections of any considerable vertical extent, to the degree to which the earlier drift was eroded by the Wisconsin ice and commingled with the later drift, and to the fact that, as it appears, the glaciers of the earlier and later advances traversing this area followed not greatly different paths, so that there is little difference in the constitution of the several drift sheets. Very few places are known to the writer where it seems at all certain that pre-Wisconsin drift can be identified.

SURFICIAL EXPOSURES OF OLDER DRIFT.

The best surficial exposures for discrimination are afforded by the bluff along the shore of Lake Michigan and the valley slopes of the lower part of Menominee River at Milwaukee.

BLUFFS OF LAKE MICHIGAN.

In the lower part of the lake bluff section near Wind Point, Racine County, in the towns of Lake and Oak Creek, Milwaukee County, and north of the mouth of Black River, and in the slopes of some of its tributary valleys in Sheboygan County, there is exposed at intervals a very dense reddish to chocolate-brown till and associated laminated clay which is very resistant to wave action. This till is thought to have been deposited at the Illinoian stage of glaciation and to be a part of the drift sheet described above as extending outside the Wisconsin terminal moraines.

Where this till occurs along the lake shore, the lower part of the bluff rises from the water's edge with nearly vertical face. So well does it withstand washing by the waves that pieces are rounded into balls and buried in the sand and gravel of the beach. Such clay balls have been found in several places in the sand and gravel overlying the dense clay in the lake bluff section and in the slopes of Menominee Valley near Milwaukee, whence it appears that even at the time of the deposition of the overlying sand and gravel the clay was very dense and resistant, probably as the result of partial cementation. It is possible that it may have been frozen. At one point in southern Manitowoc County, about 5 miles north of Northeim, this till where exposed in the lake bluff was indurated to a hard conglomerate. The laminated clay was probably deposited in the waters of a glacial lake which occupied the basin as the front of the Illinoian glacier retreated. The deposits are very much contorted, probably as the result of having been overridden by the ice of the Wisconsin invasion. North of Sheboygan the dense reddish till and contorted clay was not seen overlain by the blue till of the Wisconsin stage, as in Milwaukee County. The deposit is, however, of the same character and shows the same effects of being overridden by the glacier, so that there is little doubt that it is part of the same sheet. Were the blue till present or better exposed throughout the bluff section in Sheboygan and Manitowoc counties, the same relation might be observed.

MENOMINEE VALLEY.

Some of the best exposures of stratified beds are in the Menominee Valley near Milwaukee at the several brickyards and at Story Bros. stone quarry. At the quarry 50 to 60 feet of stratified material occurs, including dense, fine-grained, laminated red and blue clay, sandy clay, cross-bedded sand, and fine and coarse gravels, the coarser material occurring principally in the upper part of the section. At the time of the writer's visit there was a fine exposure of stratified drift on the east side of the valley southeast of Story's quarry, near the corner of Fortieth Street and Park Hill Avenue. At the bend in the valley and in the bluff north of the Chicago, Milwaukee & St. Paul Railway shops the coarser sand and gravel is in places cemented into a conglomerate, which projects in ledges from the slope. The stratified deposits are nearly everywhere overlain by variable thicknesses of buff to bluish till of the late Wisconsin stage.

SOUTH OF POYNETTE.

Two and one-half miles south of Poynette, in the SE. ¼ sec. 11, T. 10 N., R. 9 E. (Arlington Township), a cut on the Chicago, Milwaukee & St. Paul Railway exposes what may be an older drift sheet. This exposure is in the lower side slope of a small valley through which the railway ascends southward from the sandstone lowlands to the Lower Magnesian uplands of Arlington Prairie. The slope is coated with brownish clayey loam about 3 feet thick, beneath which, at one point, lies 1 foot of ashen-gray, compact, sandy till having an indefinite cleavage as though due to pressure. This till is leached of any calcareous content which it may have once contained, and the included basic and some of the acidic crystalline pebbles and bowlders, as well as those lying on its surface enveloped in the brown clay loam, are largely disintegrated. Beneath it lies 8 to 10 feet of highly calcareous reddish sandy till, from part of which the overlying gray till appears to have been developed by leaching and weathering. The line between the two tills is sharp; indeed, where seen, it appeared so sharp as to suggest that the gray upper part was an entirely distinct deposit. However, later study of the Illinoian drift beneath the loess in the northern counties of Illinois disclosed very similar conditions, the thoroughly weathered material at the top being markedly different in color, texture, and composition from the unweathered drift below, though the change, which took place within the space of a few inches, was truly a gradation. So similar are the conditions that it leads to the inference that the deposit near Poynette is of similarly weathered Illinoian drift, from whose surface the Wisconsin drift, if any, was removed prior to the deposition of the brown loess loam. Another reason for this inference is that nowhere has a weathered zone been found between Wisconsin drift and the brown loam or loess.

OCCURRENCE IN WELLS.

The thickness and character of the drift deposits penetrated by many of the wells within the area of Wisconsin glaciation also make it probable that much earlier drift is buried beneath the later deposits. In the following logs of wells, for instance, it is very probable that the deposit called "hardpan" is pre-Wisconsin glacial till. It is usually very dense and hard to drill, in which respect it differs from the overlying deposits.

Log of well in SW. ¼ sec. 5, T. 16 N., R. 23 E., Mosel Township, Sheboygan County.

	Feet.
Red till	20–25
Sand and gravel	?
Blue clay	?
Hardpan	6
Niagara dolomite	39
	199

Log of Fred Leucke's well in SW. ¼ sec. 10, T. 16 N., R. 22 E., Herman Township, Sheboygan County.

	Feet.
Red clay	15
Blue clay	95
Hardpan	12
Gravel	9
Sand Gravel	25
	156

Partial log of Fond du Lac Water Co.'s well.[1]

	Feet.
Red clay	40
Blue clay and bowlders	40–50
Hardpan, locally known as concrete	10–15
Limestone.	

[1] Data from files of Wisconsin Geol. and Nat. Hist. Survey.

Log of schoolhouse well, Harrisville, Marquette County.[1]

	Feet.
Drift	60–70
Sand	?
Cemented hardpan	30–40
Sand and gravel.	

The records of many of the wells show beds of sand and gravel intercalated between beds of clay or till, suggesting interglacial stages of water deposition, but it is not possible to make any very definite classification of the deposits shown by these records. One of the most detailed logs of the drift is that furnished by L. C. Trow, for the well at Yerkes Observatory, near the west end of Lake Geneva.

Partial log of a well at Yerkes Observatory, Williams Bay, Wis.

	Feet.
Clay	3
Dry gravel with large stones	83
Red clay	1
Blue clay	13
Red clay	28
Gravel	2
Gray clay	10
Sand	10
Fine gravel	2
Gray-colored clay	58
Sand	10
Sand and gravel	15
Sand	5
Coarser sand	8
Clay, hardpan	8
Very tough clay, not mixing well with water	13
Gray clay, no seepage of water	86
Sand	14
Gray clay	3
Sand	8
Sand and fine gravel	23
Sand with a little clay	2
Total thickness of drift	405

This series of deposits is susceptible of various interpretations, of which the following is a possible though it is by no means certainly the correct one:

Possible correlation of the deposits in well at Yerkes Observatory.

		Feet.
Clay, 3 feet Glacial morainal gravel, 83 feet Glacial clay till, 54 feet	later Wisconsin glaciation	140
Waterlaid sand and gravel (interval of glacial recession)		12
Glacial clay till (early Wisconsin glaciation)		58
Water-laid sand and gravel (interval of deglaciation)		38
Glacial clay, till (Illinoian glaciation)		107
Water-laid sand and gravel (Yarmouth deglaciation)		50
		405

[1] Data from L. A. Perkins, driller, Westfield.

It should be noted that it is by no means safe to consider deposits of sand and gravel, even if of considerable thickness, as evidence of stages of deglaciation. At all times in the vicinity of the ice front during the stage of advance, during the minor oscillations of the edge, and during the progress of the final wasting of the glacier the waters from the melting ice were apt to assort and stratify drift which a slight advance of the ice might bury in unassorted till.

ANCIENT GRAVELS IN THE ROCK RIVER VALLEY.

That considerable sand and gravel were deposited in the preglacial valley of Rock River either prior to the advance of the Illinoian ice or in connection with that advance or at both times appears from certain occurrences. About 3 miles northeast of Rockford, in what appears to be a buried portion of this old valley, E. A. Kuharske's well penetrated 154 feet of sand and gravel beneath 90 feet of till. This deposit may have been made in front of the advancing Illinoian ice and have been overridden by the continued advance and buried beneath the till which here nearly blocks the valley. At several places there are exposed in the valley slopes, uncovered or overlain by Illinoian till, gravels which may belong to this same filling or to an earlier stage. The occurrence of these gravels has been previously noted by Buell and by Leverett.[1] They are best exposed, so far as seen by the writer, up to 30 feet or so above the Wisconsin outwash terrace in the lower east slope of the valley between Harlem and Rockford, where the valley is gradually narrowing southward to the constriction formed by the Illinoian drift at Rockford; so that the gravel appears to be in the line of the old valley. In some of the exposures, as at A. Johnson's, the gravel is mostly loose and clean but partly stained buff cemented by lime carbonate and overlain by a thin deposit of sand. In other exposures, as just north of the schoolhouse, the gravel is overlain by highly calcareous Illinoian till and is partly cemented by brown to purplish-red iron oxide, though loose and buff below. The pebbles are principally of limestone with occasional quartzites and a small percentage of foreign crystallines,

[1] U. S. Geol. Survey Mon. 38, pp. 109-110, 1899.

whose presence shows that they are of glacial origin. One mile to the south, in sec. 18, T. 44 N., R. 2 E. (Guilford Township), similar gravels are exposed beneath till in the slopes of a creek valley. One mile southeast of Rockford the Illinois Central Railroad cut exposes a ridge of gravel containing masses of dark-red conglomerate, the whole being overlain by calcareous till. The cuts are now so slumped and overgrown that the exposures are poor, but Leverett states that he saw them while fresh and that masses of the conglomerate were included in the till. From this he concluded that the gravels were older than the including till, as they were already cemented when picked up by the glacier and incorporated in the drift. This drift the writer is inclined to refer to the Illinoian stage. If this is correct, the gravel is probably pre-Illinoian. Similar lime-cemented gravels were observed in creek valleys tributary to Rock River 2 miles west and 4 miles north of Oregon, Ill. It is not certain, however, that the latter deposits are to be correlated with those in the Rock River valley north near Rockford. The occurrence of similar gravel conglomerate near Shopiere has been reported by Buell.

RELATIONS OF THE ILLINOIAN AND WISCONSIN DRIFT BORDERS IN THE WISCONSIN VALLEY.

GENERAL FEATURES.

North of the town of Verona (T. 6 N., R. 8 E.) no glacial till has been found outside the moraine marking the limit of the Green Bay Glacier of the Wisconsin stage of glaciation, and no other form of glacial drift than scattered bowlders of doubtful derivation has been found to show that the early advance of the ice had a greater extension than the last advance. The trend of the drift margin in northern Green and southern Dane counties is nearly north-south, making but a low angle with the course of the moraine of the Green Bay Glacier from this place northward. A moraine rising above the plain about 2 miles outside the terminal moraine of the Green Bay Glacier in southern Portage County, about 19 miles north of the north boundary of the area under discussion, is described by Weidman,[1] who considers it much older than the Wisconsin stage. It extends northward about 20 miles in a direction nearly parallel to the margin of the later drift, beneath which it finally disappears. It is not known that this moraine (the Arnott moraine of Weidman) was formed by the same ice sheet as the pre-Wisconsin drift of southern Wisconsin, but it is not improbable that such was the case. At any rate this emergence of an older drift just outside the Wisconsin moraine seems good ground for inference that the ice margin in the intermediate points was not far within the limit reached by the later advance.

[1] Weidman, Samuel, Geology of north-central Wisconsin: Wisconsin Geol. and Nat. Hist. Survey Bull. 16, pp. 456-466, pl. 2, 1907.

BARABOO DISTRICT.

In a brief discussion of the glacial drift in his bulletin on the Baraboo iron-bearing district[2] Weidman describes certain deposits at several points west of the terminal moraine of the Wisconsin stage which he regarded as indicating that the pre-Wisconsin ice sheet had greater westward extension in that region than did that of the later stage. He refers to the scattered bowlders, some of considerable size, occurring at many places on the lower slopes and within the basin and cites Salisbury and Atwood's interpretation[3] that these came to their positions by being floated from the front of the Green Bay Glacier on bergs or floes of ice, on the waters of a temporary glacial lake held in the Baraboo basin by the ice sheet. Weidman, however, regards the bowlder noted below as probably not so deposited. He says: "On the north slope of the north range in the NE. ¼ NE. ¼ sec. 36, T. 12 N., R. 4 E., a small bowlder of gabbro was noted, 6 or 7 inches in diameter, located about 50 feet above the level of Narrows Creek immediately adjacent."

This locality is near the head of the gorge of Narrows Creek, and though it is perhaps not probable that floating ice from the glacial front 10 miles to the east swept through the gorge very often, it is certainly not impossible that it may have sometimes done so and may have dropped this bowlder and others that have escaped observation, for the lake must have extended through the gorge and far up the valley beyond. So far as known to the present writer, none of the scattered bowlders in the

[2] Weidman, Samuel, The Baraboo iron-bearing district of Wisconsin: Wisconsin Geol. and Nat. Hist. Survey Bull. 13, pp. 18 and 101-102, 1904.

[3] Salisbury, R. D., and Atwood, W. W., The geography of the region about Devils Lake and the Dalles of the Wisconsin: Wisconsin Geol. and Nat. Hist. Survey Bull. 5, p. 130, 1900.

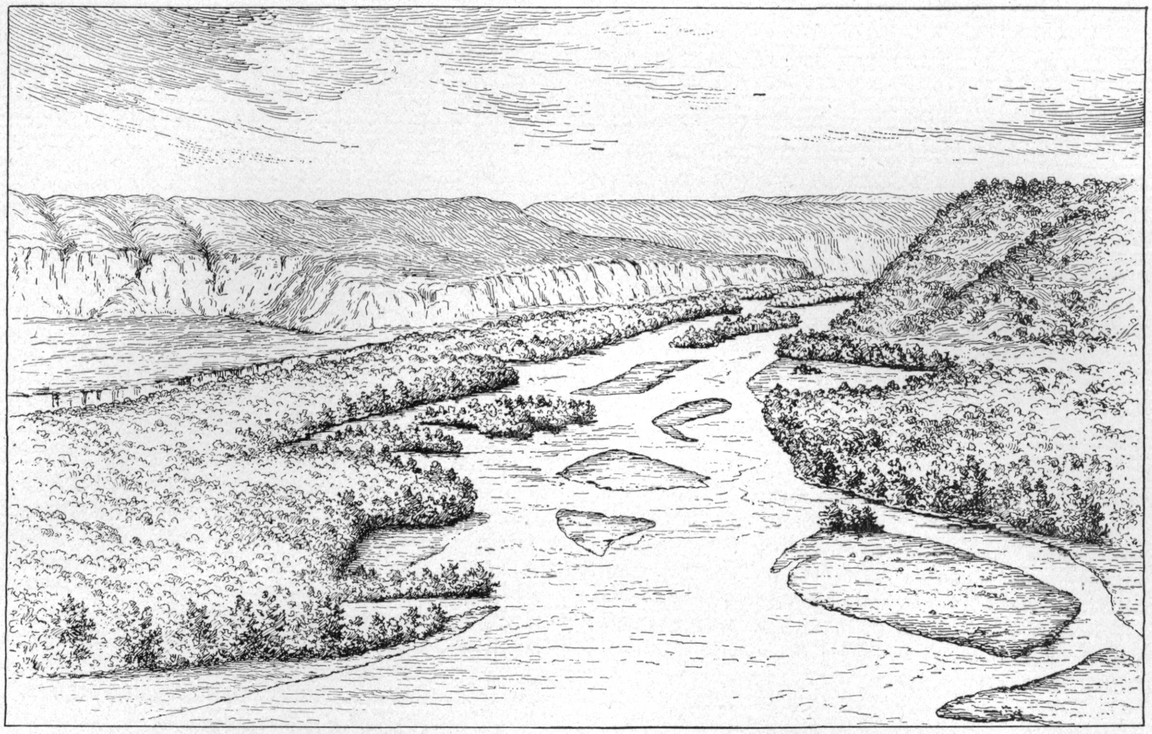
Baraboo basin or in the Wisconsin Valley north of the quartzite ranges lies above what is believed to be the surface level of the extensive glacial lakes held by the glaciers—980 to 1,000 feet above the sea. Whether or not the Illinoian glacier extended onto the Baraboo Bluffs, as did the Wisconsin ice sheet, in such a way as to block the Baraboo and Wisconsin valleys and hold therein glacial lakes of this early stage is unknown. If it did, a part at least of the glacio-natant, glacio-lacustrine, and outwash deposits in these valleys may be of Illinoian age, but, even so, they were deposited outside the limits of the ice advance and can not be regarded as evidence that the earlier ice had a greater westerly extension than the later ice. Clay, sand, gravel, and bowlders reported by Weidman as having been penetrated by borings to a maximum depth of 218 feet could have been deposited by wash and flotation from the ice front at one or another stage of glaciation, for they are not known to include unmodified glacial till. The "kettle" or depression cited as "developed in coarse drift on the south slope of the sandstone hill about one-half mile southwest of North Freedom, in the SE. ¼ SE. ¼ sec. 3," can hardly be called a "typical" glacial kettle, for outcropping ledges of sandstone are exposed in the west and north sides of the hole and sandstone blocks lie on the other sides. The present writer observed no "coarse drift" other than a few crystalline bowlders in the depression and on the adjacent slope. It seems more likely that the depression is a sink hole of some sort.

Weidman also states that there is "coarse drift outside as well as within the valley between the quartzite ranges, as instanced by an abundance of coarse drift forming hills south of the south range, north of Denzer, in sec. 10, T. 10 N., R. 5 E." Somewhat careful examination of these deposits by the writer at different times in company with other students, once in company with Weidman, failed to show the presence of any foreign material mingled with the sand, pebbles, and bowlders. The main deposit is a flat-topped ridge, 80 to 100 feet in height and about a mile in length, extending southward from the foot of the quartzite bluff at the west side of a broad ravine or amphitheater which indents the south slope of the south range. The deposit probably originally extended clear across the mouth of this ravine but has been partly removed by the deepening of the valley through the eastern part of it. The material exposed in a few places is partly gravel and partly a heterogeneous mixture of coarse and fine material that looks much like glacial drift, but the pebbles and bowlders are of quartzite and sandstone, largely well rounded, and of less well-worn pieces of chert, such as are abundant in the Lower Magnesian limestone and as occur plentifully scattered as loose fragments over the quartzite range to the north. A road cut at the south end of the ridge shows this material overlying partly disintegrated sandstone. Conglomerate of waterworn quartzite pebbles in a sandstone matrix occurs on the slopes of the quartzite range immediately to the north. The deposit may well be an ancient alluvial fan formed by deposition of the material derived from the opening out of the broad ravine or amphitheater at whose debouchure it stands. It certainly can not be regarded as glacial drift. It was formed during an earlier cycle of erosion and is now being removed by the continued excavation of the valley. Similar but smaller deposits have been observed in the lower parts of other ravines cutting the south range. Weidman regards the large angular bowlders of diorite occurring in the valley beside this ridge as of local origin and thinks them associated with a buried ledge encountered in drilling wells at the adjacent houses.

The various phenomena cited by Weidman from the Baraboo region can not be regarded as evidence that the Illinoian ice sheet extended farther west than the Wisconsin. In fact there is no conclusive evidence known to the writer that the Illinoian ice sheet extended far enough over the Baraboo quartzite ranges to obstruct the drainage of the upper Wisconsin and Baraboo valleys through the Lower Narrows and Devils Lake Gorge, even if it prevented flow about the east end of the range. There is no evidence that these gorges had been obstructed by pre-Illinoian drift deposits and, unless the Illinoian ice front reached one or both of them, the rivers must have continued in their preglacial course. (See pp. 105–107.)

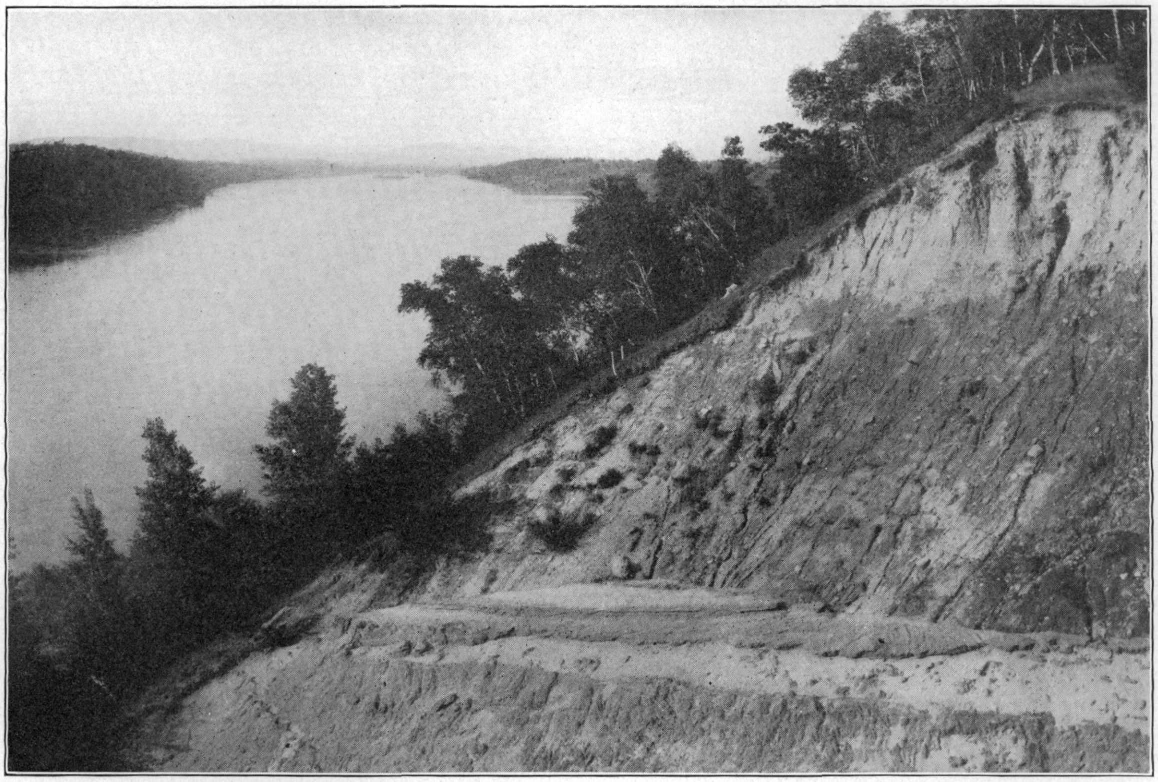
WISCONSIN VALLEY.

Certain evidences of age in the gravels of the terrace bordering the terminal moraine of the Green Bay Glacier in the towns of Sumpter



A. MOUTH OF WISCONSIN RIVER VIEWED FROM TOP OF BLUFFS ON MISSISSIPPI RIVER, SHOWING DRIFT-COVERED ROCK TERRACE NORTH OF BRIDGEPORT, WIS.

From Gen. G. K. Warren's Report, 1876.



B. LATER WISCONSIN GLACIAL MORAINAL TILL OVERLYING STRATIFIED SAND, SOUTH SIDE OF WISCONSIN RIVER 2 MILES ABOVE PRAIRIE DU SAC, WIS.

and Prairie du Sac, Sauk County, and the relations of the two terraces to the several valleys in the towns of Mazomanie, Roxbury, Berry, Black Earth, and Cross Plains, Dane County, indicate that a part of the outwash deposits in these townships may be somewhat older than the late Wisconsin advance of the Green Bay Glacier. Very careful consideration of these evidences and comparison with the results of studies on the Illinoian drift, the outwash plains, and the Wisconsin terminal moraines farther southeast, however, have convinced the writer that he is not warranted in referring the deposition of the Prairie du Sac and Mazomanie outwash gravels to waters issuing from a glacier older than the early Wisconsin substage. (See also pp. 190–193.)

PRE-WISCONSIN GRAVELS IN THE LOWER WISCONSIN VALLEY.

In several places along the Wisconsin Valley between the outer moraine of the Green Bay Glacier and the Mississippi lie remnants of glacial gravels, some, at least, of which may have been deposited by drainage from the Illinoian ice front. These were examined in part by Leverett in 1907 and again by the writer in 1909 but have received no thorough study such as would determine all their relations.

The most easterly point beyond the moraine at which these gravels were encountered is in the town of Eagle, Tps. 8 and 9 N., R. 1 W. North of the river at Muscoda an undulating tract about a mile in width, considerably dissected and mantled with loess, lies between the main bluffs and the river. Its general elevation is 730 to 750 feet above sea level, or 40 to 60 feet above the sandy plain west of Muscoda on the south side of the river. Its appearance is that of an old eroded terrace, later mantled with loess. It extends two-thirds of the way across the town of Richwood (Tps. 8 and 9 N., R. 2 W.), beyond which it has been removed by erosion. Beneath the loess on this tract the writer observed at several places pebbles of sandstone, chert, quartzite, vein quartz, and crystalline rock but none of limestone. The pebbles ranged from a fraction of an inch to 10 inches in diameter. Similar pebbles were noted on a lower sandy terrace 690 to 700 feet above sea level, which extends westward from Port Andrew. On the south side of the river the mouths of tributary valleys are partly blocked with accumulations of loess, beneath which in a few places there appear remnants of an old gravel terrace. The gravel, which was slightly exposed about 1½ and 2 miles west of Blue River, consists of crystalline, chert, and quartzite pebbles but no limestone.

At Peter Flynn's place, 3 miles southwest of Blue River, a well at the bottom of the front slope of the terrace remnant is said to have encountered small, rounded gravel at a depth of 11 feet and bedrock at 30 or 40 feet. The writer was unable to ascertain whether or not the bulk of the material composing the terrace on which the buildings stand was gravel. The elevation is about 700 feet above the sea. Most of the village of Boscobel stands on the lower terrace, which constituted the main valley plain. The southern part is on a terrace some 20 to 30 feet or more higher. The writer had no opportunity to examine the gravels of the upper terrace so as to ascertain if they were sufficiently old to have had their limestone pebbles removed by solution. If the pebbles are mostly limestone like those of the upper terrace at Mazomanie it is doubtful if they can be regarded as older than early Wisconsin. If, however, only the less readily soluble pebbles remain the gravels may be of Illinoian age or even older. Leverett [1] found gravel well exposed northwest of Wauzeka in terraces up to 740 feet above sea level—nearly 100 feet above the railway station. He states that it contains numerous stones 4 to 8 inches in diameter and notes one 14-inch granite bowlder. It contains greenstone, quartzite, jasper conglomerate, and granite as well as hard sandstone and quartz pebbles. Two terraces extend about 2 miles west of Wauzeka, where they are cut off by an old channel of the river which lies close to the base of the bluffs. In the southwestern part of T. 7 N., R. 5 W. (Wauzeka Township), there is a well-developed terrace in the lower part of Grand Gray Creek, through which the present Wisconsin has cut a channel. This terrace stands about 25 feet above the creek, or about 710 feet above sea level. Its material, so far as exposed to view, is stratified sand.

Just west of Grand Gray Creek the Wisconsin swings to the south side of the valley, leaving between it and the main line of bluffs on the north a space of nearly a mile, which for almost 6 miles is occupied by a very much eroded terrace having a maximum elevation of about 840 feet. (See Pls. XIV, *B*, p. 108, XIX, *A*, and fig. 5 (*e*),

[1] Personal communication.

p. 108.) Limestone is exposed in the bluff along the railroad to a maximum height of 50 to 60 feet above the roadbed and is also found in wells at about the same elevation (680 feet above sea level), or 80 feet above Wisconsin and Mississippi rivers. Thus, extending more than halfway across the Wisconsin Valley is a limestone terrace on which, as shown by wells, lies 60 to 100 feet of unconsolidated material, described as hard red gravel and blue clay, beneath a coating of buff calcareous loess 1 to 15 feet thick. Old weathered drift is exposed at intervals in the roads; and in one place, about one-fourth mile north of the schoolhouse (which is about a mile northwest of Bridgeport), a road cut exposes on one side 5 feet of buff loess and on the other 4 feet of brown, compact, gritty, residual drift. This drift is thoroughly leached of its soluble constituents, the pebbles being dense crystallines, quartzites, and cherts. It is like the thoroughly rotted residual layer found at the top of the Illinoian drift in the region of Rockford, Ill. Here, however, no unweathered drift was seen at any point. George Ward informed the writer that his well in the north part of sec. 9 penetrated a bed of this hard red gravel overlying sticky blue clay. At one point on the crest west of the schoolhouse, 800 feet above sea level, a bowlder of reddish quartzite, measuring 1 by 2 by 3 feet, lies on the surface. There is here, therefore, a deposit of glacial drift of considerable age extending up to a level about 800 feet or more above the sea, or 30 to 100 feet higher than the old gravels noted farther up the river. Moreover, the quartzite bowlder is too large to have been swept down the river from the Illinoian ice front in the Baraboo region unless it was borne by floating ice. Besides the evidence of age furnished by the weathered condition of the drift, the terrace was greatly dissected by erosion prior to the deposition of the loess.

It may be that this deposit has no relation to the Illinoian ice front in western Dane County. Possibly it was deposited by an ice front crossing the Mississippi Valley from the west and thrusting itself into the lower part of the Wisconsin Valley. If such was the case the drift on the Bridgeport terrace is probably of Kansan or pre-Kansan age. Were it not for evidence at other places, which has been regarded as conclusive, that the Mississippi gorge reached its maximum depth prior to the first incursion of the ice, one might be led to infer that this drift was deposited when the rock shelf which underlies it was the bottom of Wisconsin Valley and that the inner gorge and the bottom of the Mississippi gorge in this region had been excavated since the deposition of this early drift. If such really is the case, the drift probably belongs to the earliest of the ice invasions. A part of the old gravels farther up the Wisconsin Valley may be correlated with this, and a part may represent a filling by outwash from the Illinoian ice sheet. When the Illinoian ice at its maximum extension crossed the Mississippi farther south and invaded eastern Iowa a section of the Mississippi is believed [1] to have been temporarily displaced and to have flowed around the west front of the ice sheet. It is Leverett's present opinion [2] that the waters were then ponded to a height of 720 feet in the district north of the Wapsipinicon Valley and discharged past Durant, Iowa, to the Cedar, which also was greatly ponded. Thence from the junction of Cedar and Iowa rivers at Columbus Junction it discharged through a sag leading southwestward to Skunk River. From a tributary of Skunk River near Salem, Iowa, it discharged southward to the present line near Fort Madison. During the temporary occupancy of this channel by the Mississippi there must have been slack waters in the upper Mississippi and Wisconsin valleys up to the 720-foot level, or, if relative levels were the same then as now, well up into eastern Iowa County and western Dane County, Wis. This condition would facilitate the silting up of the Wisconsin Valley but would not favor the sweeping of coarse gravels far down the valley. Indeed, those which occur above the 720-foot level in this lower course seem likely to be pre-Illinoian. With the reopening of the Mississippi gorge the water level would be lowered and a higher gradient developed which might have resulted in sand and gravel deposition on some of the lower terraces near the mouth of the Wisconsin. Just what part of the filling of the Wisconsin Valley should be referred to outwash from the Illinoian glacial front in western Dane and Sauk counties can not be stated. Neither has the amount of reexcavation of the valley by the river after the melting away of the Illinoian glacier been determined.

[1] Leverett, Frank, U. S. Geol. Survey Mon. 38, pp. 89-97, 1899.
[2] Personal communication.

Chapter VII.—PHENOMENA CHARACTERIZING THE INTERVAL BETWEEN THE ILLINOIAN AND WISCONSIN STAGES OF GLACIATION.

IOWAN DRIFT.

The Iowa Geological Survey has interpreted certain deposits in northeastern Iowa as evidence of an invasion of that area by the Keewatin Glacier at a time intermediate between the Illinoian and the Wisconsin stages of glaciation and has given to these deposits the name Iowan[1] drift. This invasion is believed to have been separated from the preceding Illinoian stage of glaciation by the Sangamon interglacial stage and from the following Wisconsin stage by the Peorian interglacial stage.

CORRELATIVES IN SOUTHERN WISCONSIN AND NORTHERN ILLINOIS.

There appears to be no good evidence that there was a corresponding invasion of the Labradorean Glacier into southern Wisconsin and northern Illinois. The interval between the melting of the Illinoian ice sheet and the incursion of the glaciers of the Wisconsin stage—that is, between the beginning of the Sangamon stage of deglaciation and the close of the Peorian interglacial stage as described by Leverett[2]—was represented in this area by the superficial modification of the Illinoian drift by weathering and erosion, by the deposition of the overlying loess and loamy clay, by the formation of alluvial and lacustrine deposits, and by the growth and accumulation of vegetal material.

The character and amount of modification of the drift by weathering, which involves the development of the Sangamon soil, have already been discussed at considerable length. (See pp. 136–160.) Reference has also been made to the laminated lake clays associated with drift, probably of Illinoian age, in the bluff along the shore of Lake Michigan. (See pp. 166–167.) A part, at least, of the sand and gravel intercalated between successive deposits of glacial till, such as was penetrated by the Yerkes Observatory well (p. 168), may be the result of stream work during this interval when the land was freed from ice.

DRAINAGE DEVELOPMENT.

Attention has been directed (pp. 136–160) to the development of the reestablished drainage systems on the Illinoian drift in southern Wisconsin and northern Illinois, for the most part along preglacial courses, and also to certain places where streams were diverted from the ancient courses and forced to erode new channels in drift and rock. The most notable of these diversions[3] was that of Rock River. (See pp. 113–114.)

On the withdrawal of the Illinoian ice front to the east side of the old Rock River valley (fig. 7, p. 153) north of the mouth of Kiskwaukee River (in southern Winnebago County, Ill.), the waters ponded by the ice, which still occupied the valley farther south, found outlet and escaped southwestward to the Mississippi along several valleys and across the intervening cols in the course now followed by Rock River. The post-Illinoian stream was thus compelled to cut gorges in limestone and sandstone at several places between the point where the river leaves the old valley and Sterling. The ancient valley south of the Kishwaukee was thus abandoned and not reexcavated, so that erosive work north of this point was considerably retarded. It is not known to the writer to what depth the gorges were cut nor to what extent the valley to the north was reexcavated at that time, but it does not seem probable that it was cut down to depths greatly below that of the present stream.

The location of Rock River and the other streams during this interval of deglaciation within the limits reached by the next succeeding ice incursion and the amount of erosion accomplished there before the advance of the Wisconsin glaciers can not now be stated.

[1] Calvin, Samuel, Present phase of the Pleistocene problem in Iowa: Geol. Soc. America Bull., vol. 20, pp. 143–148, 1909; The Iowan drift: Jour. Geology, vol. 19, pp. 577–602, 1911. Alden, W. C., and Leighton, M. M., The Iowan drift, a review of the evidences of the Iowan stage of glaciation: Iowa Geol. Survey, vol. 26 (in press).

[2] Leverett, Frank, U. S. Geol. Survey Mon. 38, pp. 125–190, 1899.

[3] Idem, pp. 483–492.

That most of the development of the drainage systems on the surface of the older drift was accomplished prior to the Wisconsin stage of glaciation is probable from the fact that the work of the streams established on the surface of the later drift is generally very much less than that noted on the drift outside the terminal moraines. It is also clear from direct observation that part of the weathering and erosion of the Illinoian drift took place prior to the deposition of the loess and loamy clay which mantles its surface.

INTERGLACIAL DEPOSITS.

LOAMY CLAY, SANDY LOAM, AND LOESS.

Character and deposition.—A coating of buff, brown, or grayish loamy clay overlies the weathered and eroded surface of the Illinoian drift outside the Wisconsin terminal moraines, whence it extends westward over the residual clay and chert on the slopes and crests of the Driftless Area south of Wisconsin River and northward over the Baraboo quartzite range and onto the ridges north of Reedsburg. Locally it grades into typical loess. In Owen and Burritt townships, Winnebago County, Ill., north and northwest of Rockford, a patchy deposit of typical loess 1 to 8 feet thick extends southward to the line of the Chicago & Northwestern Railway west of Rockford, beyond which the loess is practically continuous. Here it is generally 2 to 5 feet and in places 10 to 15 feet thick.

The loess is loose and loamy in texture and buff to brownish in color. Only where the thickness is greater than 5 or 6 feet is the lower part calcareous. In such places its lower part is apt to be grayish and to show indefinite banding and, in some places in the valleys, to include interstratified beds of sand.

At the top of the east slope of the Pecatonica Valley, just north of Martintown, Wis., in sec. 32, Cadiz Township, a road cut gives the following exposure of one of the thickest parts of this deposit:

Section of loamy clay near Martintown.

	Feet.
Brown loamy clay, noncalcareous, somewhat sandy	5–7
Fine banded sandy clay and clayey sands, with lenses of bluish clay, highly calcareous below 6 to 7 feet from the surface of the ground	8–10
Stony till in road at the bottom.	

The upper part of this deposit looks very much like typical loess.

About 2 miles west of Evansville, in the SE. ¼ sec. 30, T. 4 N., R. 10 E. (Union Township) an excavation beside the road exposed 6 feet of clean buff to light-gray dustlike loess. This shows no lamination and no pebbles and is calcareous below a depth of 3 feet from the surface. The average of 60 measurements of thickness of the loess and clay loam, mostly in Rock and Green counties, Wis., is nearly 5 feet.

The typical loess seems to grade directly into the brown loamy clay which is much more widespread in the area under discussion. It appears to the writer to be one and the same deposit and it is believed to be principally a deposit of wind-blown dust. The brown clay corresponds to the upper weathered part of the loess and is thought to be a deposit of loess so thin that it has been modified throughout by leaching and oxidation and the action of the humic acids, becoming in consequence less porous and dustlike than in the thicker portions. The clay is generally not more than 1 or 2 feet thick, though thicker in places, and although almost wholly noncalcareous is quite distinct from the sticky brownish to reddish residual clay which coats the weathered surface of the limestone in the Driftless Area and at many places within the limits of the drift. It is also distinct from the weathered and unweathered portions of the till.

In some places, as east of Rock River, in Illinois, the clay is gray and rather dense, resembling the fine rock flour of the matrix of the underlying till, but is without pebbles. No fossils have been observed in either the loess or the loamy clay, but both are shown by their relations to the weathered and unweathered till and to the topography of the drift surface to have been deposited long after the Illinoian till sheet was laid down, the length of the interval being shown by the weathering of the underlying drift and the amount of its erosion. Where the drift is unaltered or little altered it is clear, not that there was no interval but rather that the weathered till was washed away before the loess and loamy clay were deposited.

A similar deposit (see pp. 341–345) mantles the surface of the later drift more or less generally as brown loamy clay but in places as typical loess. There was thus a similar deposit made after the melting of the glaciers of the Wisconsin stage. It is quite possible that some at least of the loess and loamy clay on the pre-Wisconsin drift and in that part of the Driftless Area within the district under discussion was deposited at the same time—that is, after the incursion of the Wisconsin glaciers, and that the interval between its deposition and the melting of the Illinoian ice sheet embraces not only the time from the beginning of the Sangamon stage of deglaciation to the close of the Peorian interglacial stage, but also the early and later Wisconsin substages of glaciation. Certainly the superficial alteration of the Illinoian drift by weathering and erosion appears sufficient to represent so long an interval when compared with the alteration of the surface of the Wisconsin drift. The deposit of loamy clay seems to grade into the loess, and the latter has the same characteristics as the main body of loess bordering the Mississippi Valley and is more or less continuous therewith. In central Illinois, east of Peoria, a deposit of loess overlying the Illinoian till and a Sangamon peat bed have been found underneath Wisconsin till.[1] So also in Iowa loess regarded as of the same age has been observed by the present writer and others underlying Wisconsin drift.[2]

Certain leading geologists are of the opinion that the deposition of at least part of the loess was closely associated with the presence of glacier ice. A recent statement by Chamberlin [3] is in part as follows:

> I am therefore of the rather firm opinion that a certain portion of the loess is to be interpreted as strictly contemporaneous with the presence of the ice and so dependent upon it for its distribution, mode of accumulation, etc., and that the older conceptions in this regard will be fully justified when all the facts are brought into the reckoning.

The late Samuel Calvin was of the opinion [4] that though there were deposits of loess of different ages "there is one loess that stands in intimate and close relation to the Iowan drift." In his last published paper he wrote:

> The earlier view was that the loess was deposited at the time of maximum development of the Iowan glaciation, when the Iowan area was still covered with ice. The only modification of that view at the present time is that loess deposition took place after the Iowan ice had retreated to a greater or less extent after an interglacial interval had actually begun.

Study of fossils found in many places in the loess has led Shimek [5] to the belief that much of the loess was deposited under conditions not differing greatly from those of Recent time. In some places, indeed, deposits of loess are now being made of dust whipped up from the river bottoms by the wind and carried thence on to the neighboring uplands.

No exposures seen in the part of Wisconsin under discussion or in the adjacent part of northern Illinois show the loamy clay or loess passing beneath the Wisconsin drift, so that here the evidences of its age are not decisive. It is quite possible that more than one deposit of loess is present, but no sections showing two loess deposits separated by a soil or weathered zone have been observed.

Analyses of loess and loamy clay.—At the request of the writer, J. A. Bonsteel, of the U. S. Department of Agriculture, had mechanical analyses made of samples of loess and loess loam with the results tabulated below. Analysis 1 is of typical loess taken by the writer from 5 feet below the surface on a slope about 100 feet above Wisconsin River, a few miles above its mouth, in Bridgeport Township (T. 6 N., R. 6 W.), Crawford County, Wis. Analysis 2 is a composite of samples of loess loam from the following localities: 2½ miles northwest of Denzer, Sauk County, Wis., in sec. 8, T. 10 N., R. 5 E.; sec. 30, Dellona Township, Sauk County, Wis., above the level of the glacial lake; 1 mile southeast of North Freedom, Sauk County, Wis., sec. 12, T. 11 N., R. 5 E., above the level of the glacial lake; 5½ miles northwest of Lyndon, Juneau County, Wis., sec. 22, T. 14 N., R. 4 E. (Seven Mile Creek Township), above the level of the glacial lake. Analysis 3, inserted here for comparison, is of a sample of typical loess from 5 feet below the surface, overlying buff Wisconsin till in a railway cut in sec. 28, T. 11 N., R. 12 E. (Fountain Prairie Township), Columbia County, Wis. Analysis 4, also inserted for comparison, is of a sample of laminated clay deposited in a glacial lake in sec. 6, T. 12 N., R. 6 E. (Delton Township), Sauk County, Wis.

[1] Leverett, Frank, U. S. Geol. Survey Mon. 38, pp. 128-129, pl. 11, 1899.

[2] Calvin, Samuel, Present phase of the Pleistocene problem in Iowa: Geol. Soc. America Bull., vol. 20, p. 149, 1909. Alden, W. C., and Leighton, M. M., op. cit.

[3] Personal communication, June 28, 1913.

[4] Calvin, Samuel, The Iowan drift: Jour. Geology, vol. 19, pp. 599-602, 1911.

[5] Shimek, B., The genesis of loess, a problem in plant ecology: Iowa Acad. Sci. Proc., vol. 15, pp. 57-75, 1908; The loess of the paha and river ridge: Idem, p. 124.

Mechanical analyses of loam and loess loam.

Locality.	Description.	Fine gravel, 2 to 1 mm.	Coarse sand, 1 to 0.5 mm.	Medium sand, 0.5 to 0.25 mm.	Fine sand, 0.25 to 0.1 mm.	Very fine sand, 0.1 to 0.05 mm.	Silt, 0.05 to 0.005 mm.		Clay, 0.005 to 0 mm.
							Coarse.	Fine.	
		Per ct.	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*
1. Bridgeport Township, Crawford County.	Loess	0. 0	0. 0	0. 0	0. 7	19. 6	50. 0	14. 8	14. 7
2. Driftless Area	Composite of loess loams	. 1	. 1	. 1	1. 7	18. 2	47. 1	16. 0	16. 4
3. Sec. 28, Fountain Prairie Township, Columbia County.	Loess	. 0	. 0	. 2	1. 0	5. 1	62. 6	18. 9	12. 2
4. Sec. 6, Delton Township, Sauk County.	Glaciolacustrine clay	. 0	. 1	. 0	. 4	3. 1	13. 9	35. 5	46. 9

Comparison of these analyses shows that the samples of loess loam from that part of the Driftless Area within the district under discussion and from the loess near Mississippi River to the west are very similar in their content of fine material. Sixty-three to nearly 65 per cent is silt with particles 0.05 to 0.005 millimeter in diameter, and 14 to 16 per cent is finer. The glacio-lacustrine clay is much finer, having 49.4 per cent of the fineness of silt and 46.9 per cent of finer clay with particles 0.005 millimeter or less in diameter.

LACUSTRINE AND ALLUVIAL DEPOSITS.

There are probably considerable deposits of alluvial and lacustrine silts underlying the broad flats which border Pecatonica River, Skinner Creek, Sugar, and Little Sugar rivers, much of them having probably been deposited while the glacier was present in the area. Scarcely any exposure, however, which showed their character, was noted, and it is not known to what depths they extend. The soil of the bottom land is usually sandy loam or marsh deposits. The thickness of the drift in the ridge blocking the Pecatonica Valley indicates that the filling in the valley to the north must be at least 120 feet deep, and the depth of drift penetrated by certain wells in the Sugar River basin indicates the presence of fully as much there. In the valleys of the smaller tributaries leading from the uplands one would expect to find evidence of erosion rather than deposition, yet there are certain deposits even here. Sections afforded by creek banks show in most places a deposit of black alluvium from a few inches to 10 feet thick (average, about 4 feet), underlain by 1 foot to 10 feet of nearly stoneless clay (average, 4½ feet). This clay is generally bluish, laminated, and noncalcareous. In a few places it is oxidized buff to brownish or reddish either throughout or in streaks and spots, and in some places its lower part is slightly calcareous. At the base there is generally a layer of angular chert fragments with a small intermixture of drift pebbles overlying either an uneven surface of till or the bedrock.

The following is one interpretation of the succession: After the disappearance of the ice, erosion began to strip the crests and upper slopes of the finer drift material and to reexcavate the partly filled valleys. The coarser parts of this wash were deposited along the stream beds as a layer of chert and gravel, and the fine calcareous silts were carried to the main valleys. Following this came the deposition of the loamy clay or loess, which mantles both the drift and driftless surfaces throughout the region. In the valleys the loess was largely rehandled and to it was added wash from the loamy clay on the higher slopes, giving a bed of partly laminated clay. The retention of the unoxidized bluish tint in the valley bottoms, while the color of the clay on the slopes and uplands was changed to buff or brownish, is probably due to the clay being kept moist along the watercourses. The deposit of black alluvium represents a still later stage, being the wash from the slopes since vegetation gained a foothold on the surface of the clay and developed a black loamy soil, and especially since the region became settled and cultivated by white men. The amount of black soil washed down from the plowed fields at present by heavy rains is very large; frequently it is concentrated below the lower side of the sloping field to thicknesses of 4 to 6 inches, as a result of a single torrential downpour. Much of the best soil is thus stripped from the fields to be deposited along the valley bottom.

There has been considerable silting in the valleys tributary to Sugar River as a consequence of their upper parts being occupied by temporary lakes after the melting of the ice therefrom, while their lower parts or the valley of the main stream were still occupied by the ice. The two valleys heading in Sylvester Township (T. 2 N., R. 8 W.) were left blocked by a great accumulation of drift in Decatur Township, Jordan Creek being forced to cut a new outlet through the sandstone rim of the basin 3 miles northwest of Brodhead. It is not known how much excavation of these valleys was accomplished before the Green Bay Glacier of the Wisconsin stage reached southwestern Dane and northeastern Green counties and poured its detritus-bearing waters into the Sugar River basin, retarding the further excavation by the western tributaries. The Little Sugar River valley, especially between Monticello and Albany, was probably resilted after the interval of reexcavation as a consequence of the influx of the Green Bay glacial waters, though it is not apparent how much of the outwash sand and gravel was really backed up into this valley. A marginal glacial lake in one of the tributary valleys and possibly for a time a lake occupying the whole Sugar River basin, must have overflowed through the col traversed by the Chicago, Milwaukee & St. Paul Railway between Monroe and Juda in sec. 9, T. 1 N., R. 8 W. (Jefferson Township). This outlet has an elevation of about 950 feet above sea level, so that the water would have been ponded well up to the head of the valley until the lower outlet was opened over the rim of the basin southward to the Pecatonica and thence to the Mississippi. The length of time this outlet was utilized depended on the configuration of the ice front.

VEGETAL REMAINS UNDERLYING WISCONSIN DRIFT.

With the amelioration of the climate and the melting away of the Illinoian ice sheet, vegetation gained a foothold and spread over the newly exposed surface of the drift. Deposits of peat and muck accumulated in the ponds and marshes and vertebrate and invertebrate animals took up their habitats in congenial locations. When at length a renewal of the conditions of glaciation occurred, so that the glaciers of the Wisconsin stage spread widely over parts of the area which had been previously glaciated, much of this organic material was destroyed. Trees were overthrown, and some of their trunks were incorporated in the new sheet of drift which was being spread over the surface of the old. In places beds of peat and muck were buried, and some shells and bones of animals, which escaped obliteration, are now encountered in drillings. Numerous discoveries of such organic remains beneath the later drift have been reported to the writer and are cited below.

Buried vegetal remains in the area of the Green Bay Glacier.

Marquette County.

Westfield Township (T. 16 N., R. 8 E.), sec. 15, NE. ¼. L. A. Perkins reports that in drilling a well for L. Kruger, at the latter's place 1½ miles southwest of Westfield, he penetrated 130 feet of blue clay, 50 feet of sand, 20 feet of clay, and 30 feet of sand to a 15-foot stratum of soft, greasy, carbonaceous material. Beneath this lay 120 feet of sand, through which black material is said to have been scattered. "Granite" was reached at a depth of 365 feet. Daniel Dewar's well in the village of Lawrence is also reported by Mr. Perkins to have penetrated similar black material.

Montello. Ben Neck states that in drilling a well for Christ Tagatz on the flat near Fox River logs of wood were found 20 feet from the surface.

Green Lake County.

Brooklyn Township (T. 16 N., R. 13 E.), sec. 24. H. F. Wilkie says that in drilling the well at his place, 1¾ miles northeast of the east end of Green Lake, a bed of black vegetal material containing leaves was found beneath 100 feet of clayey till.

Adams County.

New Haven Township (T. 14 N., R. 7 E.), sec. 27, NE. ¼. Charles Martin informed the writer that in drilling the well at the Big Spring creamery a black lustrous substance resembling coal was encountered beneath a considerable thickness of red and blue clay and sand. The question naturally arises whether coal may not have fallen into the well at some time when the hole was open, although the driller seemed positive that the substance was in place.

Sauk County.

Delton Township (T. 13 N., R. 6 E.), sec. 23, NW. ¼. N. Wheeler, a driller, of Reedsburg, informed F. T. Thwaites that in drilling a well for G. W. Fish, at the above location on the terminal moraine, he encountered twigs and branches of trees 260 to 270 feet from the surface. Mr. Fish informed the writer that a bed of black muck was found at a depth of 292 feet, or just above the sandstone.

Greenfield Township (T. 11 N., R. 7 E.), sec. 12. F. B. Clarke, driller at Baraboo, Wis., informed Mr. Thwaites that he drilled at Mr. Wyland's place to a depth of 234 feet before encountering the underlying sandstone. This well, if the location is noted correctly, is on the south range, about 6 miles north of Merrimac, and indicates the filling of a preglacial ravine. It is stated that muck and peat were encountered at 190 feet, above 40 feet or so of sand and fine gravel, which may or may not be Illinoian drift.

Dane County.

Middleton Township (T. 7 N., R. 8 E.), sec. 2, SW. ¼. W. J. Schneider, a well driller, states that a well drilled for John Schraeder on the flat north of Middleton penetrated 1 foot of peat beneath 100 feet of sand and above 125 feet of clay. Whether the clay is of pre-Wisconsin age or not the writer is unable to state, but he is inclined to think it is and that the 100 feet of sand overlying the peat bed represents deposition during both the advance and recession of the front of the Wisconsin ice. During the latter stage, at least, the basin was occupied by a glacial lake held in front of the retreating margin of the ice.

Middleton. Mr. Schneider also stated that the well at the post office in Middleton encountered wood at a depth of 92 feet. The well penetrated sand 60 feet, blue clay 73 feet, and sandstone.

Middleton Township (T. 7 N., R. 8 E.), sec. 8, SE. ¼. John Luth states that in drilling a well at his place in the valley about 3 miles west of Middleton 8 to 10 feet of black material was encountered beneath 80 feet of drift and above an earlier drift into which the drill penetrated 38 feet.

Madison Township (T. 7 N., R. 9 E.), sec. 16. A well drilled at L. Post's house on the small crescentic moraine was said by W. Haak, driller, to have encountered wood beneath 240 feet of drift.

Fitchburg Township (T. 6 N., R. 9 E.), sec. 9, SE. ¼. O. W. Stromme learned that a well at this place penetrated a 6-foot bed of peat beneath 112 feet of drift and above a lower bed of drift into which the drill penetrated 43 feet. This was in the filling of a preglacial valley blocked by the moraine at the head of Nine Spring Marsh.

Same, sec. 35. B. D. Riley, a driller at Oregon, Wis., informed the writer that in drilling a well for A. O. Fox about 1½ miles northwest of the village he found marsh muck with driftwood just above the sandstone, which he reached at a depth of 135 feet.

Dunkirk Township (T. 5 N., R. 11 E.), sec. 28, NW. ¼. Mr. Downer's well is said to have encountered rotten wood at a depth of 200 feet, beneath 50 feet of clay and sand and 150 feet of blue clay, and above 50 feet of sand and gravel.

Rock County.

Harmony Township (T. 3 N., R. 13 E.), sec. 23, NW. ¼. In 1886 L. M. Wilson, of Janesville, informed Frank Leverett that in drilling a well for I. E. Leake he found oily, bluish-black clay beneath 40 feet of sand and gravel and above a considerable thickness of other drift.

Same, sec. 15. From the same source it was learned that the well of Manly Wilcox, near the south border of the moraine, encountered, underneath 125 feet of drift, 15 feet of drift with several feet of black muck, including bits of wood of the size of one's finger. This overlay reddish clay.

Johnstown Township (T. 3 N., R. 14 E.). Leverett collected the following data concerning buried vegetal deposits in the vicinity of Johnstown: "Mr. J. A. Fellows dug a well about 1874 in sec. 21, Johnstown Township, on the edge of the terminal moraine, at a point about 40 feet above the outwash terrace. The well penetrated 40 feet of clay and gravel. At this depth was found a shiny, brown substance resembling coal in everything except color. In this were what looked like blades of grass. Below this was a bad-smelling, dark-colored material, in which were knotted roots and bits of wood an inch in diameter and several inches long. Below the muck gravel extended to the rock, which was encountered at a depth of 50 feet. Water from this well was at first so foul that horses would not drink it."

In their article on the Driftless Area of the Upper Mississippi Valley Chamberlin and Salisbury [1] make the following reference to interglacial deposits in this region: "Beneath the overwash gravels that fringe the moraine in the Rock River valley there are considerable accumulations of vegetable material. The wells of Johnstown, Rock County, sunk at various times during the last 30 years, have frequently penetrated these. The maximum depth of material charged with vegetal remains is several feet. The time requisite for the accumulation of this vegetable matter, while somewhat considerable, was not, geologically speaking, necessarily prolonged. Such deposits have, however, been regarded as proving distinct difference of age."

Walworth County.

Richmond Township (T. 3 N., R. 15 E.), sec. 18, NE. ¼. A well drilled on the south slope of the terminal moraine a mile west of the village of Richmond by Mr. Thorne, of Whitewater, is reported to have penetrated 2 feet of black soil just above the limestone and beneath 230 feet of clay and gravel.

Jefferson County.

Farmington Township (T. 7 N., R. 15 E.). A record of a well drilled at the Stearn place, about 2 miles southeast of the village of Johnson Creek, shows that a 4-foot bed of wood and other vegetal material was penetrated at a depth of 60 feet, and beneath this was nearly 40 feet more of drift.

Waukesha County.

Summit Township (T. 7 N., R. 17 E.), sec. 6, SE. ¼. W. S. Bolson, driller, informed the writer that in drilling Mr. Smith's well, about a mile southwest of Oconomowoc, 2 feet of soft, oily, black muck was encountered beneath 60 feet of sand and clay and above 50 feet of blue clay.

Washington County.

Hartford Township (T. 10 N., R. 18 E.), sec. 28, NW. ¼. H. Jurgen's well, about one-half mile south of Hartford, is reported to have penetrated 2 feet of black muck beneath 30 feet of sand and gravel and above a considerable thickness of blue clay and reddish clay.

Addison Township (T. 11 N., R. 18 E.), sec. 4, NE. ¼. G. Hahn's well drilled at this place penetrated 8 feet of swamp soil (and the trunk of a tamarack tree) beneath 30 feet of stony clay and above 20 feet of hard clay and 2 feet of gravel and sand.

Fond du Lac County.

Eden Township (T. 14 N., R. 18 E.), sec. 6, NW. ¼. Black sand and muck were encountered in drilling beneath 90 feet of till and gravel.

Fond du Lac. William Sealey, well driller, of Fond du Lac, states that in drilling wells on the flat plain in and about the city he has often encountered black dirt and wood at depths of 30 to 50 feet.

[1] U. S. Geol. Survey Sixth Ann. Rept., p. 264, 1885.

Buried vegetal remains in the area of the Lake Michigan Glacier.

Walworth County.

Walworth Township (T. 1 N., R. 16 E.), sec. 7.—About 1¼ miles southeast of Darien the moraine of the later drift overlaps the older drift with little or no intervening outwash. W. H. Featherstone informed the writer that in drilling his well at this place 7 or 8 feet of black quicksand was encountered at a depth of 71 or 72 feet, beneath clay, reddish gravel, yellow sand, and hard blue clay. Water from the black sand was said to taste marshy and to smell disagreeable.

Lafayette Township (T. 3 N., R. 17 E), sec. 14, NE. ¼. A well at this place is reported to have encountered a bed of black muck at a depth of 180 feet.

Bloomfield Township (T. 1 N., R. 18 E.), sec. 36. In a letter to the State geologist at Madison, under date of August 19, 1900, W. J. Miller & Sons, drillers, state that in drilling a well for Mrs. Fry within a mile east of Genoa Junction much wood was encountered between the depths of 98 and 141 feet.

East Troy Township (T. 4 N., R. 18 E.). Otto Hembrook, a well driller of Mukwonago, informed the writer that in drilling a well about 3 miles east of East Troy the following beds were passed through:

Log of a well 3 miles east of East Troy.

	Feet.
Glacial drift	39
"Fire clay"	2
Soft red "iron ore"	18
Drift	8
Limestone.	

He also stated that about 8 feet of similar "ore" was found in drilling a well at Honey Creek, about 3 miles southeast of this well, beneath 60 feet of drift. This soft, red "iron ore" and associated "fire clay" may perhaps represent an interglacial bog deposit.

Kenosha County.

Salem Township (T. 1 N., R. 20 E.). In three wells 1½ to 2 miles south of the village of Salem flows of gas were obtained from gravel beneath 50 to 60 feet of solid clay. The flow was small in amount, but it continued several years. It may have come from buried organic matter. In a neighboring well a few inches of what appeared to be lignite was encountered. Fragments of this burned on being thrown into the fire.

Milwaukee County.

Greenfield Township (T. 6 N., R. 21 E.), sec. 21. A well at the crest of the ridge 3 miles northeast of Hales Corners is said to have encountered black sand at a depth of 26 feet.

Franklin Township (T. 5 N., R. 21 E.), sec. 1, NE. ¼. In drilling a well at this place, at the depth of 24 feet black loam and a piece of float copper were encountered. About 21 feet below was a cemented layer about three-fourths inch thick, below which was 35 feet of yellow sand.

Oak Creek Township (T. 5 N., R. 22 E.), sec. 12. In 1889 a boring was made on the crest of the bluff east of South Milwaukee 105 feet above the lake. At a depth of 114 feet a bed of "dry turf" 6 feet thick was penetrated, beneath which was clay and sand 7 feet, hardpan 12 feet, and limestone.

Waukesha County.

Lisbon Township (T. 8 N., R. 19 E.), sec. 29, SE. ¼. Mr. Bennett, driller, informed the writer that in drilling a well for Mr. Byers about 2½ miles north of Pewaukee, 3 feet of black soil and wood was penetrated at a depth of about 50 feet. Beneath this the drill passed through about 37 feet of drift without reaching rock.

Washington County.

Polk Township (T. 10 N., R. 19 E.), sec. 2, NW. ¼. Michael Gruel informed the writer that in deepening a well at his place, about 4 miles northeast of Schleisingerville, a bed of black material like peat or muck was encountered at about 180 feet. From this bed, which was said to be in red clay, gas escaped until shut off by the casing. The well was drilled to a depth of 237 feet in drift. Water pumped from the lower hole was said to foam in the pail and to taste like sulphur and could not be used.

Jackson Township (T. 10 N., R. 20 E.), sec. 6, SW. ¼. August Schadz, who is himself a driller, states that when he drilled the well at his place, between 4 and 5 miles south of West Bend, he encountered, below 200 feet of clay and 50 feet of quicksand, 5 or 6 feet of black peat or turf and beneath this 110 feet more of sand. The water from this bed of vegetal material was quite black.

Although it is impossible to prove that all these vegetal deposits and buried soils were formed in the interval between the melting of the Illinoian ice sheet and the advance of the glaciers of the later stage, yet it seems probable that many do represent this interval of deglaciation. A few of them may mark pre-Illinoian deglaciation, and in those instanced below, in which vegetal deposits were found beneath red pebbly clay, they may have been accumulated in the short interval between the melting back of the glaciers of the Wisconsin stage and the readvance of the ice which brought about the deposition of the red till. They may, however, mark a pre-Wisconsin stage of glaciation.

Buried vegetal remains beneath red pebbly till.

Sheboygan County.

Holland Township (T. 13 N., R. 22 E.). George Shaver, a well driller living near Hingham, reported to the writer that he had found black muck 2 to 3 feet thick or less beneath about 60 feet of clay and above sand in several wells northwest of Cedar Grove. D. Dunn stated that in drilling his well in NE. ¼ sec. 7, about 2 miles southeast of Hingham, black muck and leaves were encountered at a depth of about 100 feet. Black muck is also said to have been penetrated below 62 feet of red till in a well in SE. ¼ sec. 23.

THEORY OF MULTIPLE GLACIAL ADVANCE.

It is not the intention of the writer to undertake in this place an exhaustive discussion of the growth of the theory that the glacial epoch was not characterized by a single continuous glacial advance and retreat. However, as Chamberlin was one of the leaders in the development of the idea of the multiplicity of the stages of glaciation and deglaciation comprising the glacial epoch, and as the phenomena which he studied in the part of Wisconsin under discussion had an important part in bringing about general acceptance of the doctrine of multiplicity of glacial advances separated by intervals of deglaciation, attention is called to a some of his papers indicating the early development of this idea. In these changes of opinion the relations of the terminal moraines recognized as belonging to the latest drift sheets played a very important part.

In a preface to a paper on the extent and significance of the Wisconsin terminal moraine,[1] which he presented before the Wisconsin Academy of Sciences, Arts, and Letters in 1877, Chamberlin stated that three years previously he had presented

some observations and conclusions in reference to a peculiar series of drift hills and ridges in eastern Wisconsin, known as the Kettle Range, and the views then advanced afterwards found a place in my report on the geology of eastern Wisconsin.[2] Similar observations were subsequently made by Prof. Roland D. Irving, of the Wisconsin Survey, and his conclusions are in perfect agreement with my own.[3]

In neither case, however, was any attempt made to show the full extent of the formations outside of the districts reported upon, or to point out its theoretical significance, the chapters being intended only as contributions to local geology, made under somewhat severe limitations of space.

Continuing with a description of the great moraine, its structure, composition, and distribution, and presenting a map of the moraine, so far as known in the various States at that time, he reached the conclusion[4] that it was "formed after the retreat of the glacier had commenced, and marks a certain stage of its subsequent history."

Proceeding further with a consideration of the glacial movements before the formation of the moraine, the method of its formation, and its significance, he says:[5]

Significance.—As 45 years have passed since Dr. Hitchcock called attention to some of the phenomena under consideration, or at least to some distinctly related to it, and yet the matter has received so little consideration that our present state of knowledge is limited to such a degree that I lay myself liable to the charge of undue temerity in attempting to correlate the observations, I may be pardoned in attempting to indicate, briefly, something of the significance and importance the foregoing conclusions, if sustained, have in relation to the Quaternary history of the region involved. The moraine constitutes a definite historical datum line in the midst of the glacial epoch and becomes a basis of reference and correlation for adjacent formations. It is an historical rampart outlining the great dynamic agency of the period at an important stage of its activity and separating the formations on either hand by a chronological barrier. * * *

If the evidence adduced to show that the Kettle moraine was due to an advance of the glaciers be trustworthy, then to the extent of that advance, whether much or little, the moraine marks a secondary period of glaciation, with an interval of deglaciation between it and the epoch of extreme advance. Its great extent indicates that whatever agency caused the advance was very widespread if not continental in its influence. The moraine, therefore, may be worthy of study in its bearings upon the interesting question of glacial and interglacial periods.

In Volume I of the Geology of Wisconsin (the last of the set of four volumes prepared under his direction), which was submitted for publication in June, 1882, and issued in 1883, Chamberlin inserted a discussion of the "second glacial epoch" and a note explaining why he had, in this volume, divided the glacial epoch in a way not done in the earlier volumes. He said:

In the descriptive volumes of this report, two distinct glacial periods are not formally stated, although the fact of

[1] Chamberlin, T. C., The extent and significance of the Wisconsin Kettle moraine: Wisconsin Acad. Sci. Trans., vol. 4, pp. 201-234, 1878.
[2] Geology of Wisconsin, vol. 2, pp. 205-215, 1877 (revised edition, 1878).
[3] Idem, pp. 608-635.
[4] Idem, p. 228 and plate. See also Chamberlin, T. C., Le Kettle moraine et les mouvements glaciaires qui lui ont donné naissance: Cong. géol. internat., sess. 1878, Compte rendu, pp. 254-268, 1880.
[5] Geology of Wisconsin, vol. 2, pp. 231-234, 1877.

a second advance, with an intervening interval, is indicated. This was due partly to the fact that investigations were still in progress, which made it injudicious to prejudge results by broad conclusions in advance of the fullest available data, and partly to the fact that the existence of two such periods had not been generally recognized by American geologists, although the doctrine of separate glacial periods had been entertained by several in this country, following the lead of the Scotch school. The only American evidence then adduced, aside from theoretical presumptions, consisted of supposed superpositions of newer upon older till, separated by supposed interglacial deposits—a class of evidence to be received with great caution, since temporary oscillations, or the shifting of subglacial streams, may produce strikingly analogous phenomena. Where the section exposed to observation chances to be parallel to the glacial margin or the course of a subglacial stream, the phenomena may seem to be much more prevalent than is really the case. A further and more important ground of doubt arises from the fact that certain subaqueous deposits so closely resemble true till that they have been mistaken for it, and there is perhaps no case of superposition of beds supposed to represent two glacial periods that is not still open to these doubts. Our present firmness of conviction arises (1) from the discovery and working out of an extended moraine stretching across the whole of the glaciated area and belonging to a system of glacial movements which differ in many important respects from the earlier ones; and (2) from the differences of surface contour due to the greater erosion of the earlier, as already indicated. We believe that this line of evidence, when developed in its fullness, will prove entirely demonstrative. Only a small part of the results now gathered fall specifically within our present province as chronicler of the geological history of Wisconsin, but the total result is, in some important measure, the outgrowth of investigations begun in this State.

Plate II, dated 1881, of the atlas accompanying the Geology of Wisconsin, distinguished the later from the earlier drift; and Plates IX and X, Volume I, Geology of Wisconsin, showed the distribution of the several glacial lobes in Wisconsin and adjacent areas during the "first" and "second" glacial epochs. In 1883 Chamberlin published[1] a preliminary paper "on the terminal moraine of the second glacial epoch," in which were maps and descriptions showing the extent of the glacial drift and the distribution of the great terminal moraine which marked off the later from the earlier drift, so far as it was known at that time. Plate XXIX of that paper shows the moraines in eastern Wisconsin practically as on Plate III (in pocket) of the present paper, differing only in minor details. In the angle of divergence of the moraines of the Green Bay and Lake Michigan glaciers a minor lobation is shown, for which the present writer subsequently[2] proposed the name Delavan Lobe. On the south side of this lobe in eastern Walworth County and western Kenosha County, near the point where Fox River (of Illinois) leaves the State, Chamberlin showed the moraine continuing southward and curving thence eastward about the head of Lake Michigan. This morainal belt, which included approximately what is now known as the Valparaiso morainic system and which is considered to mark the limit of the later Wisconsin ice advance, was then considered to be the terminal moraine of the "second glacial epoch" (now known as the Wisconsin stage of glaciation). Some light lines on the map west of this moraine represent the position of morainal ridges regarded as belonging doubtfully to this epoch.

Concerning the drift immediately outside the moraine of the "second glacial epoch" in northern Illinois, Chamberlin said:[3]

> A * * * remark may be here made concerning a considerable area in northern Illinois outside the moraine described in this paper. The freshness of its drift and the unsculptured contour of its surface bear evidence of recent origin. Some portions of this area seem clearly to be of lacustrine and fluviatile origin, at least superficially, and I have at times supposed that all might be due to waters marginal to the adjacent glacier, since there is no conspicuous bordering morainic ridge; but the tendency of recent evidence, gathered in a special study of this class of deposits, seems to favor the hypothesis of more extensive glacial occupancy, even where the evidence of it in obvious moraines is feeble or wanting. This questionable region is now under investigation. The dotted lines on the map indicate some of my working hypotheses.

Later papers by Chamberlin and his associates, especially Salisbury and Leverett, show progressive clearness of classification based upon field investigations. A paper in the Sixth Annual Report makes a separation into several subepochs, three of which are within the last or Wisconsin stage and based merely upon successive moraines, Altamont, Gary, and Antelope. Later studies showed that these divisions are of minor importance compared with divisions based upon superposition of till sheets of widely different constitution and age. The results of the investigations in the region bordering the head of Lake Michigan and neighboring parts of Illinois and Indiana are summed up in

[1] U. S. Geol. Survey Third Ann. Rept., pp. 291-402, 1883.

[2] Alden, W. C., The Delavan lobe of the Lake Michigan Glacier of the Wisconsin stage of glaciation and associated phenomena: U. S. Geol. Survey Prof. Paper 34, 1904.

[3] Idem, p. 331.

Monograph 38, in which Leverett, working under the direction of Chamberlin, presented an outline of the drift sheets and intervals.[1] A modification of this outline with some additions is presented in the present paper. (See p. 130.)

In this paper Leverett grouped as early Wisconsin a series of till sheets and associated moraines lying outside the Valparaiso morainic system to and including the Shelbyville morainic system. He considered that these had been deposited during the first extension and recession of the glaciers of the Wisconsin stage and thought that the glacial lobes, after receding to an unknown distance, had shifted somewhat and had readvanced to the moraines grouped by Chamberlin with the Kettle moraine.

In Illinois these earlier moraines spread out widely, indicating a considerably greater extension of the early Wisconsin ice than at the later readvance.

In northern Illinois, in Kane and McHenry counties, the moraines are crowded together into a single continuous belt, showing that the extension of the earlier ice was restricted, and that at the succeeding substages the ice crowded forward nearly to the same limit. The Valparaiso morainic system of the later Wisconsin glacier crowds in with the others, so as to form the eastern part of the belt. Extending northward into Wisconsin in a reentrant angle near Fox River the correlatives of the Valparaiso recurve sharply and pass about the head of Lake Geneva to the interlobate angle in the vicinity of Richmond, in western Walworth County, where they join the terminal moraine of the Green Bay Glacier. As shown by Chamberlin in 1876 [2] and later described more fully by the present writer,[3] these moraines circumscribe a small lobe of the Lake Michigan Glacier which extended from the angle of convergence of the fronts of the Lake Michigan and Green Bay glaciers in such a way as to override the northward extension of the earlier Wisconsin moraines in the vicinity of the State line. Thus the outer terminal moraines of the Green Bay Glacier and of the Delavan lobe of the Lake Michigan Glacier are believed to be the correlatives of the Valparaiso morainic system of the Lake Michigan Glacier, and possibly also the Kalamazoo morainic system of the later advance of the Wisconsin stage of glaciation. In the part of Wisconsin under discussion the later Wisconsin ice was generally more extensive than that of the earlier advance, and very little drift referable to the earlier sheet of the Wisconsin stage is exposed outside the later terminal moraines.

Some things, however, suggest that there was an earlier advance which did not differ greatly in its extent from the one that formed the moraines. First, the early Wisconsin moraines appear to pass beneath the moraines of the Delavan lobe near the south line of Walworth County and western Kenosha County. Second, in northwestern Rock County, northeastern Green County, and southern Dane County a moraine which is exposed for about 10 miles outside the terminal moraine of the Green Bay Glacier and appears to pass beneath it at both ends is thought to have been formed by an earlier extension of the Green Bay lobe. Third, certain relations of the outwash gravel terraces in the Wisconsin, Black Earth, and adjacent valleys (see pp. 191–193) suggest drainage from an ice front somewhat earlier than that of the Green Bay Glacier of the later Wisconsin advance.

EARLY WISCONSIN INVASION.

MARENGO RIDGE AND ASSOCIATED MORAINAL DEPOSITS.

The distribution of the moraines in Illinois, indicating the deployment of the ice during the earlier advances of the Wisconsin glaciers, is shown on Plate XXIII (p. 208), compiled from data obtained by Leverett. The successive drift sheets so overlap in the northern part of the State that in northern Kane County the Bloomington and Marseilles morainic systems connect with a broad morainal tract whose component parts have not thus far been satisfactorily differentiated. The outer or western border of this composite belt is occupied by a somewhat distinct moraine, called the Marengo Ridge.

Near the village of Hampshire, in northwestern Kane County, the Marengo Ridge passes by the eastern end of the outer ridge of the

[1] Leverett, Frank, The Illinois glacial lobe: U. S. Geol. Survey Mon. 38, pp. 20–21, 1899.

[2] Geology of Wisconsin, vol. 2, pl. 7, 1877.

[3] Alden, W. C., The Delavan lobe of the Lake Michigan Glacier of the Wisconsin stage of glaciation: U. S. Geol. Survey Prof. Paper 34, 1904.

Bloomington morainic system in a course nearly normal to it, and thence northward to the vicinity of Walworth, Wis., a distance of 30 to 35 miles, constitutes the outer moraine of the early Wisconsin substage.[1] Leverett states [2] that the correlation of this ridge with the moraines farther south can scarcely be said to be settled. Several interpretations are suggested by the phenomena, no one of which he considers better sustained than the others.

By the first interpretation the Marengo Ridge is considered the continuation of the Bloomington system; by the second it is made later than the outer ridge of the Bloomington system, which it would thus be considered as having overridden; by the third the outer ridge of the Bloomington system is considered to pass across the Marengo Ridge and to join the composite belt lying east of that ridge, thus referring the latter ridge to an earlier stage than the Bloomington system.

Between the Marengo Ridge on the west and Fox River on the east the composite belt, 8 to 15 miles in width, is generally morainic. In this portion also satisfactory correlations with the more clearly differentiated moraines in the districts to the south have not yet been established. Concerning these Leverett writes in part as follows: [3]

Two quite distinct interpretations have been suggested in the course of the investigation. By the first interpretation this portion of the composite belt is made to be a continuation of the inner part of the Bloomington morainic system, which connects with it near Elburn. The very strongly morainic tract immediately northeast of Elburn would, in this case, be situated at a sharp bend or reentrant angle in the ice margin, and this may account for its greater ruggedness.

The bulk of the Bloomington system is not greatly different from that of the composite belt west of Fox River, and presents no obstacle to this interpretation. The topography of the composite belt is much sharper in expression than that of the Bloomington system, but changes of topography have been found to occur in other belts to as marked a degree. * * *

By the second interpretation this portion of the composite belt is thrown into the late Wisconsin series of moraines, and its continuation found in the bowlder belts and feebly developed morainic tracts lying outside of the Valparaiso morainic system in Kane, Kendall, Grundy, and Kankakee counties. The belts can be traced into a reasonably close connection with the southern end of the undulatory belt in southern Kane County. There seems, therefore, no formidable gap to bridge in making this correlation. The greatest obstacle to the interpretation appears to be found in the abrupt change in bulk which the moraine presents in the district east of Elburn. From this point southward a thickness of only 20 or 25 feet is presented by this moraine where best developed, while to the north the thickness averages more than 100 feet. The expression also is much stronger north than it is south of this line.

Leverett further suggests a combination of these interpretations by which the great bulk of the belt north of Elburn is referred to the Bloomington morainic system, and the slight moraine in southeastern Kane County is ascribed to the later Wisconsin invasion, which is supposed to have overridden the composite belt without greatly modifying its character. The Kaneville esker northwest of Aurora, Ill., however, in Leverett's opinion, throws the balance of evidence in favor of correlation with the Bloomington system.

This latter correlation also is more in accord with the writer's observations on the relations of the Genoa and Darien moraines of the Delavan lobe, which clearly are of later Wisconsin age, to this composite morainal belt near the State line.

Near Elgin, Ill., the combined Marseilles morainic system and Minooka moraine separate from the eastern part of this composite belt. In Kendall County they divide into the component moraines, of which the Marseilles system is referred to the early Wisconsin stage, and the Minooka moraine provisionally to the later Wisconsin Glacier. From northern Kendall County northward the Marseilles morainic system appears to have been overridden by the later advance.

That the Valparaiso morainic system is equivalent to the eastern portion of the composite belt is established beyond doubt. Leverett states [4] that it probably should include all of the composite belt north of Elgin on the east side of Fox River and possibly also a small part west of that stream. This also agrees with the writer's observations on the Wisconsin side of the State line.

The relations of the moraines of Wisconsin to Marengo Ridge and the associated composite morainal belt may be stated as follows:

Marengo Ridge extends about 1½ miles into Wisconsin south of the head of Lake Geneva and ends in a long north slope which appears to

[1] Leverett, Frank, The Illinois glacial lobe: U. S. Geol. Survey Mon. 38, p. 290, 1899.
[2] Idem, pp. 295-296.
[3] Idem, pp. 302-304.
[4] Idem, pp. 304-305.

be due to its dropping down into the depression formed by the confluence of the preglacial Geneva and Troy valleys. (See Pls. II and III, in pocket.)

Where the Darien moraine crosses this trough west of Lake Geneva its crest, instead of being depressed, reaches an elevation higher than at any point northwestward to Richmond. North of the Darien moraine a broad ridge swings about the head of the Geneva basin. North of Williams Bay and the head of Lake Como, in the line of the continuation of this ridge, the Elkhorn moraine reaches the highest elevation in this part of the State—1,140 feet above sea level—though farther north this moraine is a very inconsiderable topographic feature.

From these facts it appears very probable that Marengo Ridge in descending into Troy Valley was deflected slightly toward the west. It dammed Geneva Valley near the site of the village of Walworth and thence swung toward the northeast, ascended the east slope of Troy Valley, and surmounted the Niagara dolomite.

This ridge so largely filled Troy Valley near Walworth that when the Darien moraine was deposited across the drift-filled valley its crest was not depressed but was higher than to the northwest. The elevation north of Williams Bay is well accounted for by supposing that the Elkhorn moraine here crosses Marengo Ridge as the latter ascends the preglacial slope.

The Genoa, Darien, and Elkhorn moraines lie in curves transverse to the trend of Marengo Ridge and of the whole composite morainal belt of McHenry County, Ill.; and if the writer's interpretations are correct, the northward extensions of these earlier morainal deposits were overridden by the Delavan lobe of the later Wisconsin Glacier, which formed the transverse moraines.

The Marengo Ridge just south of the State line is a bulky deposit of drift. Several wells on this were reported to the writer as penetrating 300 feet or more of drift. If the northward continuation of this was of equal bulk and is included in the filling of the preglacial Troy Valley it is not strange that this valley is so nearly obliterated by the deposits of drift. There is no good evidence as to where the west front of the Lake Michigan Glacier of this stage joined the south front of the Green Bay Glacier. It may have been within the limit of the later moraines or it may have been in the tract now covered by the outwash gravel terrace bordering these later moraines. In the southeastern part of the town of Johnstown are certain phenomena which have raised, in the mind of the writer, the question whether the Green Bay Glacier may not have extended somewhat farther south than the terminal moraine. In the SW. ¼ sec. 26, T. 3 N., R. 14 E. (Johnstown Township), about a mile south of the terminal moraine, an abrupt gravel hill or kame about 20 feet high rises above the surrounding flat outwash plain. The fact that about 70 per cent of its pebbles are from the Galena dolomite and Trenton limestone as compared with 11 per cent from the Niagara dolomite suggests that it is drift of the Green Bay Glacier deposited prior to the surrounding outwash gravels. Near the east end are some large crystalline bowlders, and in sec. 25 are numerous small sags. In the W. ½ sec. 30, T. 3 N., R. 15 E. (Richmond Township), a large depression contains gravel knolls in its bottom. The conditions suggest an earlier morainal deposit not wholly obliterated by the later outwash gravels.

BROOKLYN MORAINE.

Chamberlin called the attention of the writer to a moraine which for 10 or 12 miles lies outside the terminal moraine of the Green Bay Glacier in adjacent parts of Rock, Green, and Dane counties, and suggested that it might possibly be the correlative of early Wisconsin deposits in southern Walworth County and in northern Illinois. This moraine was mapped and described by I. M. Buell,[1] by whom it was referred to deposition during a glacial episode next preceding that at which the Johnstown moraine was formed. It carries numerous bowlders of quartzite resembling that of the Waterloo ledges, but it lies somewhat southwest of the line from the Waterloo ledges followed by the later ice, so that Buell referred it to a southwestward-moving ice sheet preceding the last deployment of the Green Bay Glacier. To this same southwestward advance he referred the morainal deposits west of Rock River in Rock County, Wis., and the southwesterly trending drumlins east of Rock River in Rock and Walworth counties, Wis., and

[1] Buell, I. M., Bowlder trains from the outcrops of the Waterloo quartzite area, pp. 492-496, 1895.

Boone County, Ill. This moraine was also mapped, though not described, in a previous publication by the present writer.[1]

This moraine, which for convenience of reference may be designated the Brooklyn moraine, appears to emerge from beneath the Johnstown terminal moraine of the Green Bay Glacier about 2 miles northwest of Evansville, in northwestern Rock County. It extends thence northwestward through the northeast corner of Green County in the town of Brooklyn (T. 4 N., R. 9 E.), into the town of Oregon in southern Dane County, a distance of 10 or 12 miles, where it again disappears beneath or merges with the terminal moraine of the Green Bay Glacier. This moraine is distinct from the Johnstown moraine, being separated from it throughout most of its length by a terrace underlain by outwash sand and gravel, varying in width from a few rods to 2 miles.

Where the Brooklyn moraine first appears in northwestern Union Township it is cut off from the front of the Johnstown moraine by a sharp little valley eroded by Allen Creek in draining the area to the northwest between the two moraines. The Brooklyn moraine extends thence northwest up the east slope of the rock ridge which formed the divide between the Sugar River basin and the tributaries of the preglacial Yahara River. It broadens from a few rods to $1\frac{3}{4}$ miles, with a relief varying from 15 to 40 feet. Reaching the crest of the rock ridge in sec. 11, Brooklyn Township, it follows this closely, changing its direction from northwest to north, until it crosses the south line of Dane County. At some places its margin lies exactly on the crest of the rock ridge, at others a few rods northeast of that crest. Where it lies to the northeast, as it does in the SE. $\frac{1}{4}$ sec. 10, Brooklyn Township, it blocked the drainage to the northeast and led to the cutting by the discharge from the ice front of a sharp ravine through the limestone crest, by which the waters escaped to the Sugar River basin. At this particular place the edge of the moraine has an abrupt relief of 15 to 20 feet. In southern Dane County the ice crossed the ridge crest and gradually descended into one of the valleys of the Sugar River basin, where it becomes more disconnected, having been cut through by the waters escaping from the Green Bay ice front as it stood at the Johnstown moraine, and is backed by outwash terraces which lead into these outlets. In secs. 7 and 8, T. 5 N., R. 9 E. (Oregon Township), the Brooklyn moraine merges with or passes beneath the Johnstown moraine and is thenceforth indistinguishable therefrom.

Although the relief of the Brooklyn moraine is nowhere very strong and indeed is generally very insignificant its surface configuration is distinctly different from the erosion topography of the thinly covered rock ridge which it crosses. From the crest of the divide in northeastern Brooklyn Township, where the rock surface is but thinly covered with a clay soil set with angular fragments of chert and scattered crystalline pebbles, one sees on the one hand a mature erosion topography, but little less strongly marked than that of the Driftless Area, and on the other hand the distinctly marked margin of the moraine with perhaps 20 feet of immediate relief and a surface scarcely touched by erosion and marked by gentle sags and swells, with occasional knolls and sharper kettles. In preglacial times the relief on both sides of this rock ridge was 300 to 400 feet, now it is 240 to 280 feet on the west and only 100 to 150 feet on the east. The present difference is due to the difference in the thickness of the drift.

Crystalline bowlders are much more abundant on this moraine than beyond its margin. Conspicuous among these are many bowlders of red quartz porphyry, some of them of large size. There are also scattered pebbles and bowlders of quartzite which appear to have been derived from the ledges of the Waterloo area.

The thickness of drift in this moraine on the rock ridge, as shown by wells, ranges from 15 to 20 feet. On either side of the rock ridge in the preglacial valleys thicknesses of 50 to 150 feet are found. From the positions of several rock exposures and the records of 19 wells the thickness of the drift in this belt is estimated at 45 to 50 feet.

As has been indicated the surface of the Brooklyn moraine is almost untouched by erosion. The effects of weathering, the amount of oxidation, and the depths of leaching of the carbonates from the drift are about the same as in the Johnstown moraine to the east, so that there seems to be little evidence of any con-

[1] The Delavan lobe of the Lake Michigan Glacier: U. S. Geol. Survey Prof. Paper 34, pl. 15, 1904.

siderable interval between the deposition of the two moraines, though they are quite distinct. It does not seem probable that the Brooklyn moraine is a branch of the Johnstown moraine formed at the limit of the last advance of the Green Bay Glacier, and that after its formation the ice front was melted back 4 miles to the present front of the Johnstown moraine. The front of the Johnstown moraine is direct, continuous, and strongly marked, evidently a unit throughout. Though it may not be provable it is the opinion of the writer that the Brooklyn moraine belongs to a drift sheet which elsewhere in this part of Wisconsin was overridden and buried beneath the deposits of the late Wisconsin glacier. It seems probable that the Brooklyn moraine, as suggested by Chamberlin, is to be correlated with the moraines of the early Wisconsin glaciers in Illinois. The deployment of the moraines in Illinois seems to indicate that the general trend of the axes of the early Wisconsin glaciers was more southwesterly than those of the later Wisconsin ice sheets. (See Pl. XXIII, p. 208.) The Brooklyn moraine lies S. 35°–40° W. from the quartzite ledges of the Waterloo district, and the last ice to cross the ledges moved about S. 15°–20° W., so that the quartzite pebbles and bowlders from these ledges must have been transported to the Brooklyn moraine by a glacier which moved in a more southwesterly direction than the last Green Bay Glacier.

As an alternative explanation, held rather lightly, it is suggested that the quartzite drift found here may have been first carried westward from the ledges by the Illinoian glacier, and later brought southwestward to the Brooklyn moraine by a movement but little discordant in direction with that of the ice of the Green Bay Glacier, which formed the adjacent part of the Johnstown moraine.

A third interpretation, regarded by the writer as poorly sustained, groups the Brooklyn moraine with the scattered morainal deposits farther south between Rock and Sugar rivers as the marginal deposits formed at one stage in the recession of the front of the Illinoian ice sheet. This corresponds with the correlation proposed by Buell except that the present writer regards the morainal deposits west of Rock River as formed at one stage in the recession of the front of the Illinoian ice sheet, while Buell regarded them as marking the limit of advance of a distinct ice sheet, to which he also referred the drumlins east of Rock River.

Although the south front of the Brooklyn moraine is clearly and in places strongly defined, running obliquely toward the front of the Johnstown moraine and there disappearing, yet a mile or so farther south, in the area west of Evansville, there is a heavy deposit of drift lying on the east slope of the same ridge, which in one place shows a distinct margin near the top of the slope and which strikingly differs both in relief and configuration from the strongly marked erosional topography thinly coated with drift on the west. Here also, at Arthur Spencer's quarry, in sec. 31, T. 4 N., R. 10 E. (Union Township), a sharp ravine cuts through the limestone crest as a result of blocking of drainage and westward discharge from the ice front at this margin similar to that noted at the margin of the Brooklyn moraine. The thickness of the drift deposit on this east slope of the rock ridge as shown by wells ranges from a feather edge to 175 feet. South of the valley of Allen Creek, however, in Magnolia and the towns to the south, there is the difficulty of distinguishing between the drift deposits to the east and west which has already been noted.

On the whole, the very slight erosion of the surface of this moraine, the freshness of its component drift, its distinctness, and its apparent emergence from and disappearance beneath the Johnstown moraine seem to favor correlation with Wisconsin rather than Illinoian moraines.

At no point north of southern Dane County, within the area under discussion, has early Wisconsin glacial drift been identified as emerging outside the later (Johnstown) terminal moraine of the Green Bay Glacier.

OUTWASH DEPOSITS.

DEPOSITS IN THE ROCK RIVER BASIN.

ROCK RIVER VALLEY.

The steep west front of Marengo Ridge is bordered by a flat plain, known as Big Foot Prairie, which is underlain by outwash gravels in the southern part of T. 1 N., R. 16 E. (Walworth Township), Wis., and extends thence southward through western McHenry County, Ill. (See fig. 7, p. 153.) In Marengo this connects with the plain in Kishwaukee

River valley, which extends westward across Boone County, Ill., to the point where the two branches of Kishwaukee River unite in the eastern part of Cherry Valley Township, Winnebago County, Ill., at the head of the post-Illinoian gorge. North of the State line in Walworth Township this plain or terrace rises gradually northward to the front of the Darien moraine of the Delavan lobe of the later Wisconsin substage, as though the gravels were deposited by streams escaping from the ice front as it stood at that moraine. Doubtless at least the uppermost gravels were so deposited, but it also seems probable that a part, perhaps the greater part, of the glacio-fluvial drift beneath this plain southward to and in the Kishwaukee Valley was deposited at the time the Marengo Ridge was being formed.

In the valley of Rock River south of the terminal moraine of the Green Bay Glacier and in the Turtle Creek valley west of the terminal moraine of the Delavan lobe, there are great deposits of sand and gravel made by waters flowing from glacial fronts, but there is no way of determining what part of the filling is to be referred to each stage.

In discussing ancient gravel deposits of the Rock River valley (pp. 168–169) it was pointed out that about 3 miles northeast of Rockford, in what appears to be a buried portion of the ancient valley of Rock River, a well has penetrated 154 feet of sand and gravel beneath 90 feet of till. This waterlaid material was evidently deposited either prior to, or in immediate connection with, the advance of the Illinoian ice sheet, and there may also have been much similar filling in the valley farther north. There is no evidence that much reexcavation of Rock River valley was accomplished in the interval following the melting of the Illinoian ice sheet. The indications are that the valley in the vicinity of Rockford continued blocked with this earlier sand and gravel overlain by Illinoian till. Kents Creek, which originally flowed directly eastward through a broad valley to join Rock River north of Rockford, now turns abruptly, leaves its old valley, and flows southward through a narrow valley which is so cut across a salient of the limestone upland in the western part of Rockford as to isolate a limestone hill in the north part of the city. The erosion of this rock gorge followed the melting of the Illinoian ice and was probably due to Rock River having been diverted through a col in the limestone ridge after the main valley had been blocked by the ridge of Illinoian drift, on which the east part of the city now stands. This would very naturally result if the till ridge which now constricts the valley at this point were continuous across to the point of the limestone ridge with a sufficiently high crest, which it probably had after the melting of the Illinoian ice, although erosion later lowered it sufficiently to permit Rock River to flow in its present course and abandon the rock gorge in the west part of the city to Kents Creek. The erosion of the drift dam which finally diverted Rock River to its present course, in post-Wisconsin time, was probably accomplished partly by the river swinging about in a sharp bend to enter the rock gorge and partly by slope wash and gullying. In this way the drift dam was sufficiently lowered to cause the stream, flowing on the additional filling received by outwash from the Wisconsin glaciers, to overtop it and begin the excavation of the present channel through the city.

The point of importance in the present connection is that there is evidence that the ancient valley of Rock River was not reexcavated after the melting of the Illinoian ice in the vicinity of Rockford, and that under these conditions it is doubtful if much of the filling was removed from that part of the valley between Rockford and the terminal moraine north of Janesville prior to the advance of the early Wisconsin ice sheets.

It is not known to what depth the rock gorges below the point where the present stream leaves its preglacial valley, 5 miles south of Rockford, were excavated; but the conditions in the vicinity of Rockford favor the idea that the valley to the south was not reexcavated much, if any, below its present depth. The reexcavation north of Rockford may not have reached the present depth of the inner valley. This also gives some check on the amount of erosion accomplished in Kishwaukee Valley and beneath Big Foot Prairie during the post-Illinoian interval. A great deposit of sand and gravel fills the preglacial valley of Rock River between the point where Kishwaukee River enters this old valley near New Milford and the point where Rock River leaves the ancient valley on the opposite side.

One excellent 30-foot section seen by the writer near the bridge over Killbuck Creek exposed stratified sand and gravel with a 5-foot bed of glacial till in the lower part. The presence of this bed of glacial till would seem to indicate that not more than the overlying 15 to 20 feet or so of stratified material had been deposited since glacier ice occupied the valley—that is, since Illinoian time.

As Pecatonica River joins the Rock River valley above Rockford and as Sugar River is a tributary of the Pecatonica there is presumptive evidence that none of these valleys were reexcavated to any considerable extent during the post-Illinoian interval and that, therefore, no great part of the valley filling is to be referred to the glaciers of the Wisconsin stage. This is in consonance with the evidence in Sugar River and tributary valleys.

VALLEYS TRIBUTARY TO ROCK RIVER.

The continuance uneroded of the 120-foot filling of Illinoian drift in the tributary valley southwest of Dayton with so slight an outlet in the soft sandstone rim by the stream draining the basin above appears to be conclusive evidence that the Sugar River valley has not been reexcavated since the Illinoian stage. The stream here, which drains a basin of nearly 9 square miles, has not yet cut down to the level of Sugar River a mile away, and the filling above is almost wholly undissected, a condition which it is unlikely would be found had the main stream cleared out its valley at any time. Several other diverted streams draining basins not much if any larger on the older drift have cut deeper gorges in the limestone. Those other streams, however, had not filling high enough below the drift dams to interfere with their downcutting.

Another rock gorge that resulted from diversion of drainage on the disappearance of the Illinoian ice and that is particularly significant in the matter of the filling and reexcavation of the Sugar River valley is that in sec. 17, T. 4 N., R. 9 E. (Brooklyn Township), 3 miles north of Attica. At this place a small stream comes down from the upland on which lies the Brooklyn moraine. At the head of the valley, which is of preglacial origin and was never wholly filled by Illinoian drift, are two small Pleistocene rock gorges cut in the ridge crest where the Brooklyn moraine lies a little east of the divide in such position that the glacial waters were forced to cross the divide to escape to the southwestward. Thus it seems quite clear that at this place not only the ordinary drainage since the disappearance of the Illinoian ice sheet, but also glacial waters from an ice frontage of nearly 2 miles during the time the Brooklyn moraine was being deposited and ordinary drainage since the disappearance of the ice sheet, have discharged down the valley to Sugar River. In the S. ½ sec. 17, Brooklyn Township, a drift ridge blocks the outlet of this valley and the present stream draining the basin above flows through a narrow gorge in St. Peter sandstone. South of the dam it flows out upon the filling of the main valley, which is here 2 miles in width. This gorge has clearly never been cut deeper and refilled. As in the case cited above, it seems impossible that this gorge could have continued so small and shallow in friable sandstone if the main valley immediately to the south had ever had its filling removed.

Jordan Creek is another stream whose valley is of like import. It drains a basin of about 20 square miles in adjacent parts of Decatur and Sylvester townships, Green County. In preglacial time it was a broad valley tributary to Sugar River near Brodhead with a width of 2½ miles between the crests of the ridges forming the rim on either side. The valley was partly filled with drift during the Illinoian stage of glaciation and the broad outlet west of Brodhead is blocked by a ridge of drift in which wells have penetrated to depths ranging from 25 to 168 feet before reaching rock. One well 175 feet deep in the deepest part of the ancient valley did not reach the bottom. The present stream drains the basin through a narrow rock gorge or sharp ravine 100 feet in depth which cuts through the sandstone rim, at a point where the overlying cap of Trenton limestone has been removed, and cuts 5 or 10 feet into the Lower Magnesian limestone at the edge of the present flood plain of Sugar River. This gorge also has unquestionably never been deeper than it is at present, whence it seems improbable that Sugar River has flowed at any considerably lower level since the Illinoian ice disappeared. The drift plain of Jordan Creek basin is almost entirely unmodified by erosion, the surface, except the upper slopes at the head of the basin, being as slightly gullied as that of the later Wisconsin drift sheet. The relations at the outlets of the other tributary valleys are not such as throw any light on the question.

Wells in the northeastern part of Decatur Township are said to penetrate blue clay, probably till, to depths of 40 to 164 feet, along what appears to have been the main channel in the ancient valley. This at least seems to be a part of the Illinoian filling. The present flood plain, however, southward to within 3 miles of the State line, is bordered on the east by a flat sandy terrace about 10 feet above the stream, like that found farther north. The eroded margin of this terrace exposes stratified sand gravel with some not very coarse gravel in beds dipping southward.

The following partial log of the artesian well at Brodhead, preserved by William Roantree and Dr. R. Broughton, shows in detail the character of the filling of the ancient valley at this place:

Partial log of artesian well at Brodhead, Wis.

	Feet.
Sandy soil	2
Yellow sand	50
Yellow sand and gravel	48
Blue clay and sand	12
Black sandy loam	4
Very fine hard yellow clay	2
Yellow clay and quicksand	12
Yellow clay, blue gravel, and coarse red sand	6
Total thickness of drift	136

Beneath the drift was rock apparently belonging to the lower part of the St. Peter sandstone or the upper part of the Lower Magnesian limestone.

From this record there appear to have been two stages of filling in the ancient valleys, the lower 24 feet representing the first stage and the soil developed on its surface. Samples of the drillings penetrated above 148 feet were not seen by the writer and he can not certify that this first (24-foot) filling was really glacial drift. It seems doubtful if this is all that can be referred to the Illinoian stage of glaciation, and so far as is yet known there was no earlier glacial invasion of this region. It may in reality be a pre-Illinoian fluviatile deposit, and the overlying 112 feet of sand, gravel, and blue clay may represent the work of glacial drainage during the advance and retreat of the Illinoian ice sheet. It seems rather strange, however, if the valley has not been reexcavated in post-Illinoian time, that the section should contain no representative of the heavy clay till found west of this valley.

The well at the schoolhouse in sec. 29, T. 1 N., R. 10 E. (Avon Township), is said to have penetrated 175 feet of clay without reaching rock, and one in the NW. ¼ sec. 30 passed through 128 feet of solid blue clay before reaching sandstone. It is hardly probable that outwash would furnish such a thickness of solid clay at this place. It seems more likely that it is the Illinoian drift.

If the amount of refilling in the Sugar River valley is to be divided between the drainage of the earlier and the later Wisconsin glaciers there is thus a very moderate amount to be referred to each.

If the post-Illinoian Rock River, while cutting the rock gorge in the western part of the city of Rockford, Ill., meandered through the old valley above that point and removed the filling down to a gradient similar to that of Wisconsin River between Portage and the Mississippi (an average fall of 1½ feet per mile), the valley plain north of Janesville when invaded by the early Wisconsin ice sheet must have had an elevation of about 150 feet below the present plain or approximately that of the present stream.

If this is what occurred the deposits made by waters flowing from the early Wisconsin ice fronts may constitute a large part of the sands and gravels lying above this erosion level and underlying the great gravel plains which border the later moraines. In none of the exposures has there been noted anything indicating a distinction between the earlier and later deposits. The amount of erosion of the outwash deposits which has been accomplished in some places has sometimes raised the question in the mind of the writer whether most of the deposition of the outwash sand and gravel in the area under discussion was not accomplished in connection with the early Wisconsin invasion and whether the work of the waters from the later Wisconsin glacier was not confined principally to erosion of the earlier-formed deposits.

Evidences of the amount of this erosion are to be seen in the valley of Turtle Creek bordering the Darien moraine of the Delavan lobe;

in the small valley extending southwestward through the southeastern part of T. 3 N., R. 13 E. (Harmony Township), to Rock River at Janesville and other similar valleys; and in the low elevation of the gravel plain in Marsh Creek valley west of Rock River in the town of Janesville, as compared with that to the east.

The relations of the gravel terrace to the broad marsh-bottomed tract through which Allen Creek flows for about 2 miles south of Evansville, on the west side of the creek, are such as to suggest deposition of the gravels by early Wisconsin waters and erosion by the drainage from the late Wisconsin ice front. Between 2 and 4 miles northwest of Evansville a gravel terrace, locally known as Jug Prairie, rises gradually northward to the south front of the Brooklyn moraine; and here again the question arises whether these gravels are not the outwash from the early Wisconsin ice. This terrace is separated from the front of the later Wisconsin moraine by the narrow valley of Allen Creek, which likewise cuts off the earlier from the later moraine.

Evidence to confirm these various suggestions has not, however, been found, so that the description and history of the outwash deposits in the Rock River valley is treated much as in the writer's previous paper on the Delavan lobe,[1] being discussed in connection with the description of the deposits of the later Wisconsin glaciers. (See pp. 238–244.)

Where the Brooklyn moraine lies on the slopes and crest of the big limestone ridge, there is evidence, as noted above, that the waters escaped westward down valleys tributary to Sugar River, but in none of these places are gravels found to have been washed from the early Wisconsin glacier.

DEPOSITS IN THE WISCONSIN RIVER VALLEY AND ITS TRIBUTARIES.

WISCONSIN RIVER VALLEY.

The relations of the outwash gravel terraces in the Wisconsin and tributary valleys are somewhat more critical and require more detailed discussion.

Distribution of outwash.—Irving's first map [2] of the glacial drift and Quaternary deposits of central Wisconsin locates the terminal moraine somewhat differently from the later maps. It shows drift outside the moraine all through the western part of Dane County and does not indicate outwash deposits in the Wisconsin or other valleys, nor is there any particular discussion of them in that connection.

Chamberlin, dealing in later papers with the distinctive phenomena of the earlier and the later drift, makes frequent reference to the extensive outwash deposits extending down these and other valleys from the front of the glacier of the "second" epoch of glaciation, and regards them as indicative of stronger outflow from the later than from the earlier ice and thus as evidence of greater relative elevation of the glaciated area during the later epoch of glaciation. On the general map of the Quaternary formations of Wisconsin issued in 1881 [3] the presence of lacustrine and fluviatile drift beyond the general drift area is shown by dots in the Wisconsin and some other valleys.

In 1883, under the title Valley drift, reference is made to the deposition of outwash material from the Green Bay Glacier as follows: [4]

> The Green Bay Glacier discharged largely through the Rock River valley, filling up its old channel to a depth of 350 feet (including the débris left by the earlier glacier) with a deposit of finely assorted sand and gravel, producing a beautiful level plain 3 to 5 miles wide, and extending 40 miles or more southward from the moraine. A considerable discharge from the west side of the glacier passed down the Sugar River and spread over its valley a sand plain of equal extent. From the Madison lake region there was a discharge westward into the Wisconsin River. * * * That portion of the glacier which lay across the lower Wisconsin Valley of course discharged its waters down that channel, giving rise to gravel terraces, remnants of which still bear witness to the fact.

On the Quaternary map of the Driftless Area and its environs,[5] glacial flood drift of the later epoch is mapped in the lower Wisconsin Valley from the terminal moraine of the Green Bay Glacier to Mississippi River but not in Black Earth and adjacent creek valleys. Of these deposits the following description is given: [6]

> The most notable flood train originating on the actual border of the driftless region is that which stretches down the valley of the Wisconsin River. The edge of the ice lobe crossed the Wisconsin in the western part of Dane and Sauk counties. In the immediate valley of the river the moraine is largely composed of gravelly constituents, dis-

[1] U. S. Geol. Survey Prof. Paper 34, pp. 38-40, 1904.

[2] Irving, R. D., Geology of central Wisconsin: Geology of Wisconsin, vol. 2, pl. 25, *A*, 1877.

[3] Geology of Wisconsin, Atlas, pl. 2, 1881.

[4] Geology of Wisconsin, vol. 1, pp. 284-285, 1883.

[5] U. S. Geol. Survey Sixth Ann. Rept., pl. 27, 1885.

[6] Idem, pp. 261, 262.

posed in kamelike hills and ridges or undulatory and pitted plains, showing the combined action of wash and push on the part of the glacier and its waters. Originating from this gravelly moraine there stretches away a flood train of gravel and sand, reaching down the valley to the Mississippi, and, there joining similar gravel streams originating higher up, it continues down through the Driftless Area and beyond, though only remnants now remain. This valley drift originates at a height of about 90 feet above the present level of the Wisconsin River, and as it stretches down the valley gradually declines, so that, as it leaves the driftless region, it is barely 50 feet above the Mississippi. Near its origin coarse cobbles, bowlderets, and even occasional bowlders are not infrequent. Farther down the material becomes finer, and in the lower stretches only pebbles and sand are found. The lessening coarseness of the deposit seems to show that as the glacial waters issued from the edge of the ice they were overloaded and struggling with a burden too great for their complete mastery; and, while they successfully carried the silt, sand, and even some of the finer gravel far down their courses, the heavier material in large part lodged near its origin and progressively filled the bottom of the channel.

Discrimination of the drift.—Critical study of these deposits, however, has raised some question as to their all being referable to drainage from the later glacial advance.

In the Wisconsin Valley above Prairie du Sac the terminal moraine of the later advance of the Green Bay Glacier overlies a deposit of stratified sand which is exposed in the bluffs on either side of the river to a height of about 60 feet. (See Pl. XIX, *B*, p. 170.) This stratified sand is such as might have been washed from the front of an earlier glacier lying somewhat east of the limit of the last advance. It continues west of the river beneath the terrace which borders the front of the moraine. Underlying this terrace but above this level is also some gravel and sand. The terrace, known as Sauk Prairie, is so related to the moraine that one would say at once that it was underlain by outwash material deposited when the moraine was formed, and it is probably true that at least the upper part near the moraine was so deposited at the later Wisconsin substage. However, the drift of the moraine contains a high percentage of limestone pebbles, but throughout the 30 square miles or more of the terrace one sees only a few limestone pebbles among those exposed at the surface or in cuts 2 to 5 feet deep. Almost all the pebbles near the surface are of the less readily soluble rocks, such as chert, crystallines, sandstone, and quartzite. For convenience this may be called residual drift gravel. Wells indicate that gravel runs in streaks beneath the terrace and is not everywhere present. A few cuts show an abundance of limestone gravel below 2 to 5 feet from the surface. One cut near the schoolhouse, a mile south of Pains Corners, which the writer examined in company with Weidman, showed 2 feet of sand and sandy clay at the surface, underlain by 1 to 2 feet of sand and residual gravel, beneath which was 20 feet of stratified sand and gravel, 73 per cent of the pebbles of which were limestone. The material exposed in this cut differs lithologically in no respect from the drift of the moraine, less than a mile to the east, but the limestone pebbles have evidently been removed from the upper part by solution of downward percolating waters. This cut is also in a slope where more or less of the material at the top may have been removed by wash. The gravel has thus been exposed long enough for considerable leaching action to have taken place.

The terrace has also been considerably eroded by Otter Creek, which has excavated a valley 30 to 60 feet in depth with a flat bottom nearly one-half mile in width in places. West of this valley there is a similar terrace, or a continuation of the terrace blocking the mouth of the Honey Creek valley which has a width of nearly 2½ miles. Gullies in this sandy terrace 10 to 20 feet deep show but little gravel. Limestone pebbles are found only in the bottoms of the deeper gullies.

Estimates of the composition of these gravels made at two points west of Otter Creek in in secs. 32 and 5, T. 9 N., R. 6 E., Prairie du Sac Township, showed the following percentages, respectively: Chert, 46 and 49 per cent; sandstone, 8 and 7 per cent; quartzite, 15 and 19 per cent; crystallines, 30 and 25 per cent; red shale, 1 per cent. These pebbles are mostly smoothed, rounded, and polished.

A short abrupt marginal slope extending southwestward from the vicinity of Prairie du Sac is the boundary between this upper terrace and a lower one which evidently was developed by the erosive action of Wisconsin River, as it shifted laterally across the plain. Excavations in this lower terrace show limestone gravel which in places has been subjected to considerable weathering. One pit, 1½ miles west of Sauk City (also examined in company with Weidman), gave the following section:

Section of outwash gravel west of Sauk City.

	Feet.
Black soil and brown sand with few pebbles	2–2½
Dark-brown sand containing chert, quartzite, sandstone, and crystalline pebbles but no limestone pebbles except rotten ones in the lower part	2–2½
Stratified waterworn gravel, 70 per cent limestone, 10 per cent quartzite, 10 per cent chert, and 10 per cent crystalline pebbles	3–4

In places pipes of the weathered middle stratum extend 2 to 3 feet downward into the stratified gravel. The amount of alteration by weathering at this place even raised the question whether the gravels might not be as old as Illinoian. There certainly would be ground for such an inference if it were known that the 20 feet or more of outwash material which was removed in forming this lower terrace was all thoroughly leached of its soluble constituents and that the weathered material exposed in the above section is only what is left of a much deeper zone of weathering. As it is, however, after careful consideration, the writer has not felt justified in referring all this outwash deposit to a pre-Wisconsin stage of glaciation. It seems probable, however, that there must have been much deposition in the preglacial valley at the Illinoian stage; and it also seems doubtful if much of it was removed during the interval prior to the incursion of the early Wisconsin glaciers.

Although much of the outwash may have been deposited by waters from the glacier of the Wisconsin stage, some things seem to indicate two stages in the filling. If the first of these stages was not the Illinoian, it may have been that of the earlier advance of the Wisconsin stage, as has been suggested to the writer by Chamberlin.

The second terrace ends in an abrupt marginal slope, which extends westward across the valley from just below the Sauk City railroad bridge. Below this, extending over about 22 square miles of the southern part of Prairie du Sac and Mazomanie townships, is a broad marshy plain, from most of which the sand and gravel have evidently been removed by the meandering of Wisconsin River (if the upper terrace ever extended continuously southward to Mazomanie, as remnants along the foot of the eastern bluffs indicate that it did).

Just north of the village of Mazomanie a remnant of an upper gravel terrace, corresponding in elevation with the upper Sauk Prairie terrace, extends from the mouths of Halfway Prairie Creek and Black Earth Creek valleys westward about 5½ miles to Blue Mounds Creek, 2 miles east of Arena. This terrace is peculiar in the vicinity of Mazomanie in that it extends into only two (Halfway Prairie Creek valley and Black Earth Creek valley) of the four valleys tributary to Wisconsin Valley including and north of Black Earth Creek valley. It blocked the mouths of the first and third valleys with dams about 20 feet high, which were subsequently cut through by the drainage from the marshy bottom valleys. Evidently gravel-bearing waters, which built this upper terrace, issued from the second and fourth valleys but not from the first and third, and this, in spite of the fact that the marginal drift ridge marking the limit of later Wisconsin advance of the Green Bay Glacier can be traced continuously across all four of the valleys and the intervening bulky rock ridges, which are 100 to 250 feet in height.

The only way which has suggested itself to the writer of accounting for this condition is the following: Valleys 1 and 3 are short and head less than 2 miles east of the marginal drift ridge and consequently may have discharged waters from only the last of the ice sheets. Valleys 2 and 4 head much farther eastward and are indeed through valleys, connecting by narrow cols with the Yahara River basin. These valleys may thus have afforded outlets for gravel-bearing waters from an earlier ice sheet, possibly an early Wisconsin glacier, whose front lay across these longer valleys but which did not invade the heads of valleys 1 and 3. Conditions would thus be afforded for building an upper terrace extending down the Halfway Prairie Creek valley and the Black Earth Creek valley and spreading out in the Wisconsin Valley. Valleys 1 and 3 were never graded up to the level of the upper terrace in the Wisconsin Valley. In valley 1 gravels are exposed in the creek banks within 100 rods of the limit of the ice advance, which is in the SW. ¼ sec. 32, T. 9 N., R. 7 E. (Roxbury Township), but to the west they pass below the level of the marsh, which is graded to the level of the big marsh tract in the Wisconsin Valley. These gravels evidently represent the later Wisconsin outwash.

In valley 3 the limit of glaciation is near the schoolhouse in the NE. ¼ sec. 20, T. 8 N.,

R. 7 E. (Berry Township). Westward, down the valley, the bottom is all marsh and shows only dark sand. At the mouth of the valley in the NE. ¼ sec. 15 (Mazomanie Township), the creek cuts through the upper terrace which blocks the valley's mouth in a narrow ravine to drain the marsh. Where crossed by the west line of Berry Township, the terrace in Halfway Prairie Creek valley (No. 2), which is graded up to the upper terrace in the Wisconsin Valley, is about 60 feet higher than the marsh level on the same line in valley 1 to the north and 20 to 30 feet higher than the marsh level on the same line in valley 3 to the south.

The upper terrace in the vicinity of Mazomanie has an elevation of 795 to 800 feet and is composed principally of sand but contains a small amount of fine to coarse (2-inch) gravel. Limestone pebbles are plentiful below the surface but have been removed by solution from the upper part of the sections. So also pebbles left in the bottom of "blow outs," or hollows a few feet deep, excavated by the wind, are almost wholly of relatively insoluble rock such as chert, quartzite, and dense crystallines. The railway cut about 3 miles west of the Mazomanie in the SW. ¼ sec. 13, T. 8 N., R. 5 E. (Arena Township), exposes 25 to 30 feet of finely stratified sand with cross-bedding dipping westward in the direction of flow down the valley. This terrace is bordered on the north by a 30 to 50 foot abrupt, eroded, marginal slope, dropping down to the marsh on the north. For 1½ miles east of Blue Mound Creek it is bordered on the north by a remnant of the lower terrace lying about 740 feet above sea level.

The southern part of the village of Mazomanie is built on a remnant of the upper terrace. Most of the village is built on the second terrace, 782 ± feet above sea level, which was developed by erosion by the outflow from the Black Earth Valley, probably in connection with the later Wisconsin ice invasion. Into this second terrace the stream has cut its present channel and developed a lower, narrow, flood plain by meandering. There are considerable remnants of the upper terrace on either side of the valley, and above the village of Black Earth the upper terrace spreads out broad and flat. The lower terrace, which is nearly 20 feet below the upper at Mazomanie, is only 8 feet below it at Black Earth village. A short distance farther up, the lower terrace rises to the level of the upper, and finally, within 2 or 3 miles of the village of Cross Plains, it merges with the front of the later Wisconsin terminal moraine, and itself becomes the upper terrace. The gravel in this part of the valley is coarser, containing pebbles up to 6 and 10 inches long. It is largely limestone, clear, fresh, and sound, and is but little weathered even at the surface. The relations indicate that sand and gravel bearing waters from an earlier glacier, sweeping down the valley to the Wisconsin, built the upper terrace of the Black Earth Valley. In the succeeding interval of recession of the ice front doubtless some erosion was accomplished. Then, when the Green Bay Glacier advanced to the site of Cross Plains and formed the terminal moraine, coarse outwash material was deposited, mostly between the sites of Cross Plains and Black Earth villages, grading up the valley, while the waters continuing down the valley cut into the earlier terrace, developing the second terrace by erosion and grading to a level corresponding with the flow in Wisconsin Valley. The second terrace continues down the valley as a broad sandy plain. The upper terrace terminates at Blue Mound Creek about 4 miles west of Mazomanie. Nothing has been observed by the writer to indicate that it extended farther down the valley, although it may have done so.

DEPOSITS IN THE HONEY CREEK VALLFY.

The valley of Honey Creek in the towns of Honey Creek, Franklin, and Troy, Sauk County, is occupied by a broad flat alluvial plain which extends far up toward the heads of the valley before reaching an elevation higher than 820 feet above sea level. This is the level of the top of the deposit between Honey and Otter creeks, to which the blocking of the valley and the consequent silting up appears to have been due.

At one point 2 miles east of Witwen the creek bank exposes 5 feet of sand over reddish calcareous clay. No recognizable glacial material was seen at this point or farther west, but the fact that the clay is calcareous indicates that it is probably a glacial silt, laid down in ponded waters at the time of the filling of the valley east of the creek, whether at the later Wisconsin substage or earlier. The well at Witwen creamery penetrated sand 16 feet, blue clay 15 to 16 feet, sand 38 feet. A 20-foot bank, where the creek has cut into the deposit in sec. 32, exposes finely laminated sand over stratified sand and clay. The penetration in a well one-fourth mile southwest of Leland of a bed of black muck beneath 30 to 45 feet of sand and above other sand probably indicates two stages of filling separated by an interval of exposure during which the muck accumulated in a marsh. A neighboring well is said to have penetrated sand to a depth of 100 feet, so that the filling before this interval may have been equal in amount to that deposited since.

It looks as though the filling in this valley came from two opposite sources, that in the upper part of the valley, which has a clayey soil over the sand, being wash from the slopes and uplands with perhaps a coating of loess loam, and that in the lower part of the valley, including the calcareous clays, being a glacial wash from the east. In the upper plain the stream has cut down about 15 feet, developing a lower and narrower flood plain. This opens out as a broad plain 1 to 2 miles west of Witwen. Farther east the stream has cut into the second plain, forming a still lower narrow flood plain and leaving remnants of the second as a bordering terrace near the town line. Between the town line and Lodi mill, on the sand plain which lies just west of Otter Creek, the stream cuts a valley 60 feet in depth and flows out across the big marsh flat to the Wisconsin.

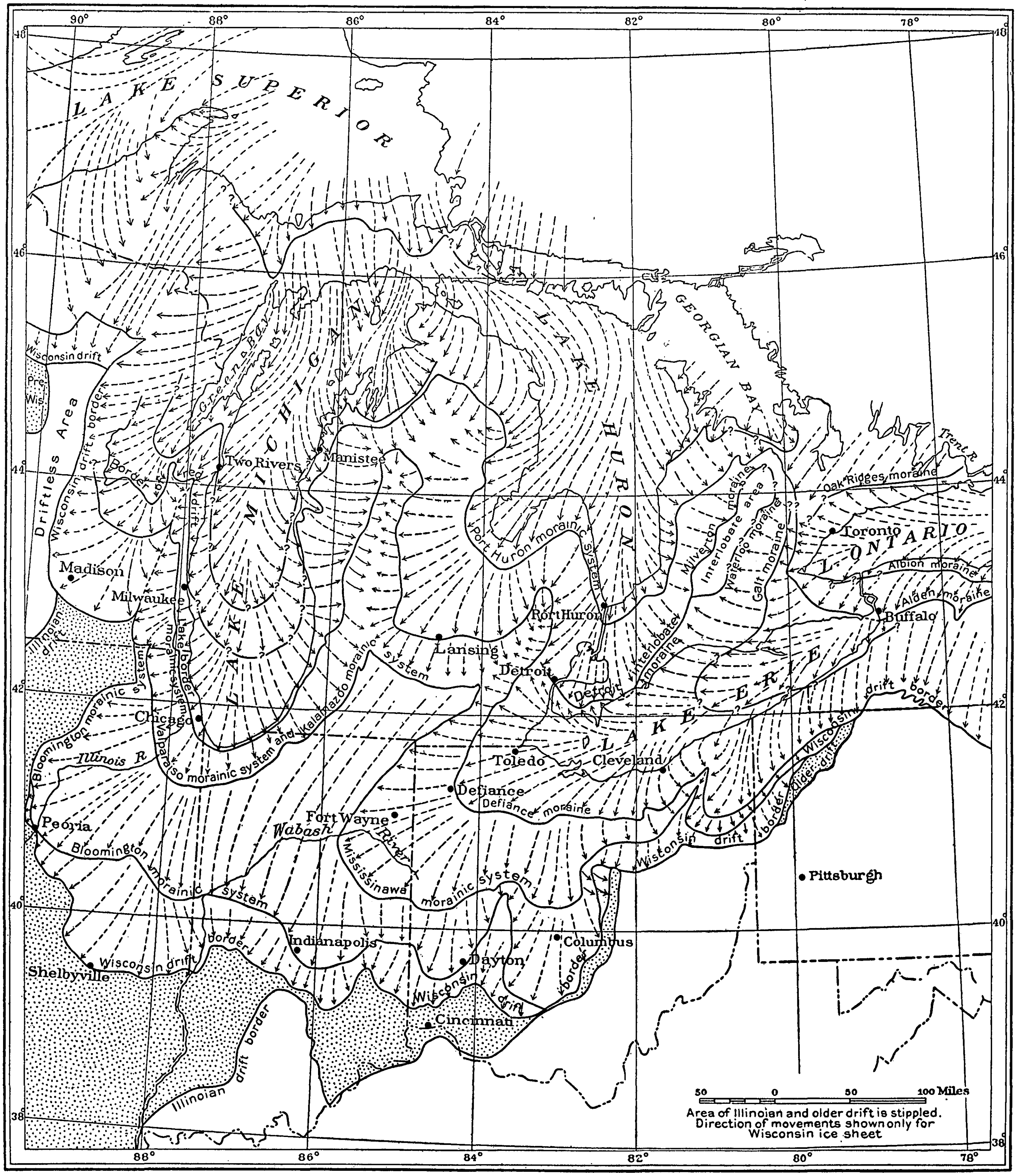
DEPOSITS IN THE BARABOO AND UPPER WISCONSIN VALLEYS.

The relations of the fronts of either the Illinoian or the early Wisconsin glaciers to the Baraboo quartzite range are not known, and positive statement as to the age of the deposits in the Baraboo basin and in the Wisconsin Valley north of the quartzite range is not possible. The Illinoian ice front may have encroached on the east end of the quartzite range and may have discharged detritus-bearing waters into the Baraboo basin and the Wisconsin Valley both north and south of the Baraboo Bluffs, but the writer knows of no conclusive evidence that this ice sheet pushed so far westward as to block the Lower Narrows and Devils Lake gorges and to create temporary lakes in these valleys. It may have done so, but the evidence is not at hand to prove it. If the terrace deposits south of the quartzite range, described above as probably of early Wisconsin age, were really made by the outflow from the Illinoian ice sheet, then it is probable that the Baraboo and Upper Wisconsin valleys were filled at the same time to corresponding levels with either glacial, lacustrine, or alluvial sediments. If, however, the Wisconsin Valley did not receive a filling of glacial outwash at the Illinoian stage, or if any that was deposited was removed wholly or in part by erosion prior to the incursion of the early Wisconsin ice, then the deposits in the Baraboo and upper Wisconsin valleys were probably laid down in connection with the early Wisconsin invasion, for it seems clear that the valley south of the quartzite range was filled prior to the later Wisconsin glacial advance.

The uppermost exposed deposits underlying the flat bottom of the Baraboo basin west of the terminal moraine and the bordering sand and gravel terrace both above and below the Upper Narrows are laminated calcareous silts (lacustrine sediments derived from unweathered drift) and not alluvium derived from residual clays washed from adjacent slopes. From this and other evidence it is concluded that the silts were deposited in a temporary glacial lake held in the Baraboo basin by the blocking of the Devils Lake Gorge with glacial ice and drift. The elevation of the top of these clays is 880 to 900 feet above sea level. Similar clays in the Wisconsin Valley north of the range in Adams and Juneau counties extend in most places where seen up to about the same level, but in some places they rise 40 to 50 feet higher.

Sauk Prairie terrace, south of the quartzite range, rises to 880 or 900 feet above the sea at the terminal moraine, but it is not known to have been quite so high when the early Wisconsin outwash was being deposited. There is thus no certainty that lakes of the requisite depth could have been or were held in the Baraboo and upper Wisconsin valleys prior to the last advance of the ice.

It is known that not only the channel about the east end of the range (if one had been previously opened) was closed but also that both the Lower Narrows and the Devils Lake gorges were closed by drift and ice at the advance of the later Wisconsin glacier, so that the only safe interpretation seems to be to refer at least the uppermost of the lacustrine deposits in the Baraboo and upper Wisconsin basins to deposition in temporary glacial lakes retained by the drift and ice of the Green Bay Glacier of the



DIAGRAMMATIC REPRESENTATION OF SUCCESSIVE POSITIONS OF ICE BORDER.

By Frank Leverett, F. B. Taylor, W. C. Alden, and Samuel Weidman.

later Wisconsin incursion. The deposits in these basins are therefore discussed in connection with the phenomena of the later Wisconsin glaciation. (See pp. 222–230.)

In that discussion certain evidence is presented which seems to indicate that part of the deposits were laid down at an earlier stage, following which there was an interval when the Baraboo basin was drained, soil was formed, vegetation grew, and trunks, branches, and leaves of trees, marsh muck, bones of animals, and small shells accumulated. Later the basin was flooded and sand and lacustrine silts were deposited.

Whether the first stage of deposition was preglacial, or was associated with the Illinoian or early Wisconsin stages of glaciation, or is to be correlated with an intervening stage of deglaciation is not known.

RETREAT OF THE ICE FRONT.

It is not known to what extent the ice of the early Wisconsin glaciers melted away before a readvance of the glaciers occurred. Possibly Wisconsin was wholly freed from ice. The relative disposition of the moraines of the early and later stages in Illinois and Indiana has been regarded as indicating a considerable shifting of the ice lobes when the glacial fronts again advanced and this was thought to imply extensive deglaciation of the region of the Great Lakes. At present, however, this interval is regarded as of minor importance. Little is really known about the deployment of the early Wisconsin ice in Wisconsin, and the area under discussion furnishes no evidence regarding the extent of the deglaciation or the length of the interval before the readvance occurred.

LATER WISCONSIN INVASION.

DEPLOYMENT OF THE GREEN BAY AND LAKE MICHIGAN GLACIERS.

GREEN BAY GLACIER.

As the ice of the later advance of the glaciers of the Wisconsin stage invaded Wisconsin the troughs formed by the erosion of the soft beds of the Cincinnati shale became the controlling factors of the separation and deployment of the Green Bay Glacier and, in the southeastern counties, of the formation of the Delavan lobe of the Lake Michigan Glacier. The preglacial valleys seem not to have been obliterated by the earlier drift deposits.

The Green Bay–Lake Winnebago trough was competent to give direction to the Green Bay Glacier but was not sufficiently deep to confine it. On the west the ice spread out 60 to 70 miles from the main axis of the lobe. (See Pl. XX.) In western Shawano County and eastern Marathon County, where the ice encroached upon the Archean rocks, the marginal deposits are nearly 1,000 feet higher than at the bottom of Green Bay, opposite Sturgeon Bay.

In Winnebago County, where the ice entered the Fox River valley, the movement shifted from southwesterly to westerly and the striated crystalline ledges of southern Waushara County show the direction to have changed to 20° to 30° north of west. Ascending the gently sloping surface of the Galena dolomite in western Fond du Lac County, the ice entered the heads of the westward-discharging valleys or descended the marginal escarpment and continued westward through Green Lake and Marquette counties across the lowlands formed by the preglacial Fox and Wisconsin river valleys. (See Pls. I, II, and IV, in pocket.) Crossing the Wisconsin Valley the ice reached the limit of its advance and laid its terminal moraine along the western slope of the preglacial valley through adjacent parts of Marquette, Adams, Columbia, and Sauk counties. The ice advancing up the slope of the Galena dolomite from Fond du Lac County into Dodge County deployed very widely, as shown by the remarkable system of radiating drumlins and by striæ observed on many exposed rock surfaces. Some of it, swinging westward, crossed the Lower Magnesian limestone upland in Columbia County, descended the bordering escarpment, overrode the marginal erosional hills, and crowded far up onto the crest of the Baraboo quartzite. On the lower lands north and south of the bluffs and in the Baraboo basin between the ranges the ice completely blocked the Lower Narrows and Devils Lake gorges, ponding the waters over the lowlands to the west and producing extensive temporary lakes.

The ice crossing southern Dodge County spread widely, radiating over Dane and Jefferson counties, the northern part of Rock County, northwestern Walworth and western Waukesha counties to the terminal arc of the south end of the lobe. In this part the ice deployed over the area drained by Rock River and its tributaries, apparently paying little heed to the directions of the preglacial valleys, which doubtless were largely filled with earlier glacial drift.

On the east the deployment of the ice reached only 20 to 30 miles from the axis of the lobe. This limitation was not, however, wholly due to the escarpment formed by the west margin of the Niagara dolomite and the underlying shales, for southward to southwestern Waukesha County the ice overrode the escarpment and began to descend the gentle eastward slope of the Niagara formation.

LAKE MICHIGAN GLACIER.

The Lake Michigan Glacier advanced southward along the lake basin and on the west deployed laterally into the eastern counties of Wisconsin, where its west front moved 8 to 30 miles up the gentle rock slope. Where the opposing fronts of the Lake Michigan and Green Bay glaciers met on this slope the advance ceased and the Kettle Range, or Kettle interlobate moraine, was formed.

Most of the striæ observed along the lake trend southwestward, but those observed farther west, together with the drumloidal ridgings, lie nearly normal to the trend of the interlobate moraine.

In Illinois, Indiana, and southwestern Michigan the Kalamazoo and closely succeeding Valparaiso morainic systems are believed to mark the limit of the advance of the Lake Michigan Glacier at this stage. The relations of certain outlying features have not been clearly determined.

In southern Waukesha and Walworth counties, Wis., before reaching the limits of its advance, the west front of the Lake Michigan Glacier crossed the divide and entered Troy Valley. This valley, through Walworth County, has a breadth of 10 to 15 miles and its bottom lies 300 to 500 feet below the level of the higher parts of the rock surface on either side. To what extent it was filled with drift of the earlier ice invasions is not known, but evidently it offered a channel of easy flow to the ice nearing the limits of its advance on the gently rising slope of the Niagara dolomite, for the ice descended it to the vicinity of Richmond, Darien, and Walworth, or nearly 25 miles farther west than the limit reached in Illinois. Delavan, in western Walworth County, stands not far from the most southwesterly point reached by this glacial lobe, so that the name Delavan lobe is a convenient term by which to designate this part of the Lake Michigan Glacier.[1]

Though the origin of the Delavan lobe appears to have been due in large part at least to the channel of easy flow offered by the Troy Valley, the lobe, once initiated, was not confined to the limits of the valley but spread southward over a more elevated tract between Elkhorn and Burlington and over the lower area to the south (in which is the Geneva Valley), until its south front halted near the State line along the northern border of the composite morainal belt formed by the earlier glacial advances of the Wisconsin stage.

STRIÆ.

The trend of certain striæ observed at several places within the limits of the late Wisconsin invasion of the Green Bay Glacier (see p. 163) is more southwesterly than the apparent trend of the late Wisconsin ice movements in those particular vicinities, as shown by the orientation of drumlin axes and by other striæ. It is possible that these southwesterly trending striæ were graved on the rock during an earlier Illinoian or Wisconsin ice advance and escaped obliteration by the ice of the later advance. In the first of the following tables is listed glacial striæ observed by the writer and his assistants at 143 different rock exposures in the area of the Green Bay Glacier, including those at 5 exposures noted above as of possibly earlier origin and including those at 10 exposures a short distance north of latitude 44° N. Striæ were also previously reported from many of these localities by T. C. Chamberlin and R. D. Irving.[2] In the second table are listed the bearings of glacial striæ reported by these latter observers from 37 exposures within the area of the Green Bay Glacier but not seen by the writer and his assistants.

[1] Subsequent to the publication in 1904 of "The Delavan lobe of the Lake Michigan Glacier of the Wisconsin stage of glaciation and associated phenomena" (U. S. Geol. Survey Prof. Paper 34) the writer learned that G. L. Collie had in 1901 proposed the name "Geneva" for this lobe of the Lake Michigan Glacier in a paper on the Physiography of Wisconsin (Am. Bur. Geography Bull., vol. 2, pp. 270–287). For this oversight the present writer offers his apologies to Prof. Collie. In the latter paper the lobe was merely mentioned, named, and shown on a somewhat distorted sketch map. In Prof. Paper 34 elaborate maps, detailed description, and elucidation of its history and relations were presented. In view of this it is hoped the present writer will be pardoned for retaining the name Delavan for the lobe.

[2] Geology of Wisconsin, vol. 2, pp. 200, 201, 205, 625, 1877.

With these are listed one observation each by Leverett and Thwaites. In the third table are recorded observations of glacial striæ at 29 exposures in the area of the Lake Michigan Glacier made by the writer and his assistants; and in the fourth are the bearings of striæ at 4 exposures noted by Chamberlin but not seen by the present writer and his assistants. This gives a total of 172 observations of glacial striæ made during the present survey and 41 additional observations made by other observers within the limits of the late Wisconsin glaciation in the area under discussion. To this total should also be added 4 (see p. 163) made by I. M. Buell within the area of the Green Bay Glacier but regarded by him as of earlier origin. This gives a total of 217 observations within the limits of the later drift and 5 observations in the area of the pre-Wisconsin or Illinoian drift north of the Illinois-Wisconsin State line.

Striæ of the Green Bay Glacier observed by the writer and his assistants.

West of the axis of the lobe.

WINNEBAGO COUNTY.

	Trend.
Algoma Township, T. 18 N., R. 16 E.:	
Sec. 27, SE. ¼. Frank Last's quarry at Knapp and Thirteenth streets, Oshkosh, on Galena dolomite	S. 33°–36° W.
Sec. 27, NE. ¼, just southwest of Oshkosh. Robt. Lutz's quarry, on Galena dolomite	S. 37°–55° W.
Rushford Township, T. 18 N., R. 14 E., sec. 9, NE. ¼. Lower Magnesian limestone in road	S. 85° W.
Nepeuskun Township, T. 17 N., R. 14 E., sec. 3, NW. ¼. Lower Magnesian limestone in road	S. 96° W.

WAUSHARA COUNTY.

Marion Township, T. 18 N., R. 11 E.:	
Sec. 22, SE. ¼. Granite ledge	S. 120°–127° W.
Sec. 23, SE. ¼. Granite ledge beside road	S. 120° W.
Sec. 24, NE. ¼. Granite ledge, E. Tetzlaff's land	S. 100°–120° W.
Sec. 27. NE. ¼. Granite ledge, Milwaukee Granite Co	S. 95° W.

FOND DU LAC COUNTY.

Ripon Township, T. 16 N., R. 14 E.:	
Sec. 20, NW. ¼. Quarry south of road in Trenton limestone	S. 52°–54° W.
Sec. 28, northwest corner. Quarry in Trenton limestone in south part of Ripon	S. 67°–92° W.

Striæ of the Green Bay Glacier observed by the writer and his assistants—Continued.

West of the axis of the lobe—Continued.

FOND DU LAC COUNTY—continued.

	Trend.
Metomen Township, T. 15 N., R. 14 E., sec. 28, SE. ¼. Ledge of Galena dolomite on O. B. Knapp's land	S. 44°5–4° W.
Waupun Township, T. 14 N., R. 15 E., sec. 33, SW. ¼. On Galena dolomite at S. M. Randall's quarry in northeast part of Waupun	S. 29°–30° W.

GREEN LAKE COUNTY.

Berlin Township, T. 17 N., R. 13 E., sec. 11, SE. ¼. On Lower Magnesian limestone ledge in road	S. 163° W.
Brooklyn Township, T. 16 N., R. 13 E.:	
Sec. 13, NW. ¼. On Lower Magnesian limestone ledge in road	S. 48° W.
Sec. 14, SW. ¼. On Lower Magnesian limestone ledge in road	S. 46°–65° W.
Sec. 35, NE. ¼. Lower Magnesian limestone ledge at mouth of Mitchell's Glen; faint	S. 90° W.
Green Lake Township, T. 15 N., R. 13 E.:	
Sec. 25, W. ½. On Trenton limestone in road	S. 32° W.
Sec. 29, E. ½. On Trenton limestone in road	S. 67° W.
Sec. 29, SE. ¼. On Trenton limestone on Chas. Clavon's quarry	S. 60° W.
Sec. 32, NE. ¼. On Lower Magnesian limestone in road	S. 62° W.
Sec. 33, SW. ¼. On Trenton limestone quarry on L. Dansmore's land	S. 60° W.
Seneca Township, T. 17 N., R. 11 E., sec. 2, SE. ¼. On Pine Bluff, a knob of granite	S. 60°–73° W
Princeton Township, T. 15 N., R. 12 E., sec. 28, N. ½. On Lower Magnesian limestone in road	S. 75° W.
Marquette Township, T. 15 N., R. 11 E.:	
Sec. 34, NE. ¼. On rhyolite ledge, 1½ miles southwest of village	S. 94°–123° W.
Sec. 2, NW. ¼. On rhyolite ledge ½ mile southeast of above	S. 90°–103° W.

MARQUETTE COUNTY.

Montello Township, T. 15 N., R. 10 E. Montello Granite Co.'s quarry at Montello	S. 83°–103° W.

Striæ of the Green Bay Glacier observed by the writer and his assistants—Continued.

West of the axis of the lobe—Continued.

MARQUETTE COUNTY—continued.

	Trend.
Buffalo Township:	
T. 14 N., R. 10 E., sec. 8, SW. ¼. On Observatory Hill, rhyolite	S. 101°–135° W.
T. 14 N., R. 9 E., sec. 13, NE. ¼. On rhyolite ledge on John Stone's (?) land	S. 97°–120° W.
Moundville Township, T. 14 N., R. 9 E., sec. 8, NW. ¼. On ledge of rhyolite ½ mile east of Endeavor; faint	S. 122°–130° W.

DODGE COUNTY.

	Trend.
Chester Township, T. 13 N., R. 15 E. On Galena dolomite at Randall's quarry, 1 mile southwest of Waupun	S. 29°–37° W.
Oak Grove Township, T. 11 N., R. 15 E. On Galena dolomite at A. H. Bussewitz's quarry, ½ mile NW. of Juneau	S. 0°–15° W.
Trenton Township:	
T. 13 N., R. 14 E., sec. 29, SW. ¼. On Galena dolomite, on J. B. Cochrane's (?) land	S. 41° W.
T. 13 N., R. 14 E., sec. 30, SW. ¼. On Galena dolomite south of road	S. 44° W.
T. 13 N., R. 14 E., sec. 32, SW. ¼. On Galena dolomite at Peter Smith's quarry	S. 39°–41° W.
T. 12 N., R. 14 E., sec. 16, NW. ¼. On Galena dolomite, on E. Propst's land	S. 32°–34° W.
Beaver Dam Township, T. 12 N., R. 14 E., sec. 34, NW. ¼. On Trenton limestone, ½ mile east of Beaver Dam, on north side of railway; faint	S. 32° W.
Shields Township, T. 9 N., R. 14 E., sec. 12, E. ½. On Galena dolomite in road	S. 5°–10° E.
Portland Township, T. 9 N., R. 13 E.:	
Sec. 27, NW. ¼. On quartzite of island ledge	S. 20°–36° W.
Sec. 27, W. ½ SW. ¼. On quartzite ledges	S. 5°–20° W.
Sec. 33, SE. ¼. On quartzite of the quarry ledge	S. 15°–29° W.
Sec. 35, SE. ¼. On quartzite, 1½ miles northwest of Hubbleton	S. 20°–35° W.

COLUMBIA COUNTY.

	Trend.
Randolph Township, T. 13 N., R. 12 E.:	
Sec. 1, SE. ¼. On Lower Magnesian limestone in road	S. 72°–84° W.

Striæ of the Green Bay Glacier observed by the writer and his assistants—Continued.

West of the axis of the lobe—Continued.

COLUMBIA COUNTY—continued.

	Trend.
Randolph Township, T. 13 N., R. 12 E.—Continued.	
Sec. 9, NE. ¼. On Lower Magnesian limestone in road	S. 74°–75° W.
Sec. 13, NE. ¼. On Trenton limestone at small quarry	S. 75° W.
Fountain Prairie Township, T. 11 N., R. 12 E., sec. 34, NW. ¼. On Lower Magnesian limestone in railroad cut, 80 rods northwest of Fall River station	S. 45°–50° W.
Columbus Township, T. 10 N., R. 12 E.:	
Sec. 3, SE. ¼. On Lower Magnesian limestone at small quarry 2 miles northwest of Columbus	S. 46°–49° W.
Sec. 36, NE. ¼. On Trenton limestone at small quarry north of road	S. 42° W.
Marcellon Township, T. 13 N., R. 10 E.:	
Sec. 7, NE. ¼. On rhyolite ledge east of road; faint	S. 75° W.
Sec. 7, SW. ¼. On rhyolite ledge near Elmo Morgan's house north of church; faint	S. 90° W.
Sec. 30, SW. ¼. On Cambrian sandstone in road	S. 65° W.
Leeds Township:	
T. 9 N., R. 10 E., sec. 4, E. ½. On Lower Magnesian limestone in road	S. 70°–85° W.
T. 10 N., R. 10 E., sec. 17, E. ½. On Lower Magnesian limestone in road	S. 76°–86° W.
T. 10 N., R. 10 E., sec. 26. Near southwest corner of Lower Magnesian limestone in road	S. 75° W
Fort Winnebago Township, T. 13 N., R. 9 E., sec. 36, NW ¼. On Cambrian sandstone at Herman Kutzke's quarry	S. 70°–85° W.
Arlington Township, T. 10 N., R. 9 E.:	
Sec. 10, near southeast corner. On Lower Magnesian limestone in road	S. 79°–114° W.
Sec. 28, NE. ¼. On St. Peter sandstone in road	S. 87° W.
Caledonia Township:	
T. 12 N., R. 8 E	S. 85° W.
T. 12 N., R. 8 E., sec. 27, NW. ¼. On Cambrian (?) sandstone on the Baraboo quartzite range	S. 87° W.
T. 12 N., R. 8 E., sec. 34, NW. ¼. On Baraboo quartzite	S. 90°–100° W.

Striæ of the Green Bay Glacier observed by the writer and his assistants—Continued.

West of the axis of the lobe—Continued.

COLUMBIA COUNTY—continued.

Trend.

Caledonia Township—Continued.
- T. 11 N., R. 8 E., sec. 4, SW. ¼. On Baraboo quartzite........S. 83°–87° W.
- T. 11 N., R. 8 E., sec. 5, NE. ¼. On Baraboo quartzite in road......................S. 125° W.

SAUK COUNTY.

Fairfield Township, T. 12 N., R. 7 E.:
- Sec. 21, SE. ¼. On Baraboo quartzite....................S. 65° W.
- Sec. 25, NW. ¼................S. 80° W.

Greenfield Township:
- T. 12 N., R. 7 E., sec. 26, NW. ¼. On Baraboo quartzite on crest of west bluff at Lower Narrows.........................S. 80° W.
- T. 12 N., R. 7 E., sec. 30, SE. ¼. On Cambrian sandstone, 2 miles northeast of Baraboo ....S. 100°–105° W.
- T. 12 N., R. 7 E., sec. 32, middle north line. On Baraboo quartzite ....S. 92°–95° W.
- T. 11 N., R. 7 E., sec. 3, middle S. ½. On Cambrian basal conglomerate in road.........S. 80° W.
- T. 11 N., R. 7 E., sec. 11, SE. ¼. On Baraboo quartzite in road......................S. 50° W.

Baraboo Township, T. 11 N., R. 6 E., sec. 2, NE. ¼. On Cambrian sandstone at Pratt & Burke's quarry.S. 63°–67° W.

DANE COUNTY.

Cross Plains Township, T. 7 N., R. 7 E., sec. 1, NE. ¼. On Lower Magnesian limestone (bearing not read) (?)........................SW.

Dane Township, T. 9 N., R. 8 E.:
- Sec. 1, NW. ¼. On Lower Magnesian limestone............S. 88°–90° W.
- Sec. 7, middle south line. On Lower Magnesian limestone in road..........................S. 86° W.
- Sec. 15, SW. ¼. On Lower Magnesian limestone at small quarry......................S. 75°–80° W.
- Sec. 15, south line, SW. ¼. On Lower Magnesian limestone in road..........................S. 75° W.

Springfield Township, T. 8 N., R. 8 E.:
- Sec. 16, W. ½. On Lower Magnesian limestone in road......S. 97° W.
- Sec. 21, W. ½. On Lower Magnesian limestone in road......S. 68° W.
- Sec. 21, NE. ¼. On Lower Magnesian limestone at old quarry hole.................S. 64°–79° W.

Striæ of the Green Bay Glacier observed by the writer and his assistants—Continued.

West of the axis of the lobe—Continued.

DANE COUNTY—continued.

Trend.

Middleton Township, T. 7 N., R. 8 E., sec. 34, middle. On Trenton limestone in road (bearing not read)..........................(?) SW.

Vienna Township, T. 9 N., R. 9 E., sec. 14, NW. ¼. On Lower Magnesian limestone at Chris Johnson's quarry.....................S. 67°–70° W.

Westport Township, T. 8 N., R. 9 E.:
- Sec. 10, SE. ¼. On Lower Magnesian limestone at Martin O'Malley's quarry...........S. 60°–65° W.
- Sec. 26, NW. ¼. On Madison sandstone at railroad cut, northwest of Mendota station.S. 45°–65° W.
- Sec. 36, SE. ¼. On Mendota limestone at railroad cut......S. 68°–70° W.

Madison Township, T. 7 N., R. 9 E.:
- Sec. 21, NW. ¼. On Lower Magnesian limestone at David Stephen's quarry, 1½ miles west of the University of Wisconsin.......................S. 55°–60 W.
- City of Madison, east of Fourth Ward School, at Brooks and Chandler streets. On Mendota limestone..............S. 25°–43° W.
- Sec. 29, SE. ¼. On Lower Magnesian limestone in Illinois Central R. R. cut; faint......S. 37°–50° W.
- Sec. 25, E. ½. On Lower Magnesian limestone in road.....S. 60° W.

Windsor Township, T. 9 N., R. 10 E.:
- Sec. 14, south line SW. ¼. On Trenton limestone in road....S. 56°–58° W.
- Sec. 26, east line NE. ¼. On Lower Magnesian limestone in road.........................S. 50° W.

Burke Township, T. 8 N., R. 10 E.:
- Sec. 26, NE. ¼. On Lower Magnesian limestone hill southeast of Burke station [1]............S. 65°–73° W.
- Sec. 27, NW. ¼. On Madison sandstone at small quarry 1½ miles west of Burke station ..S. 32°–35° W.
- Sec. 33, NW. ¼. On Mendota limestone at Andrew Lillick's quarry......................S. 33°–45° W.

Blooming Grove Township, T. 7 N., R. 10 E., sec. 11, NE. ¼. On Trenton limestone at A. G. Estes quarry...............S. 30°–38° W.

Dunn Township, T. 6 N., R. 10 E., sec. 23, SE. ¼. On Cambrian sandstone, point on west shore of Lake Kegonsa............S. 12°–23° E. and S. 23° W.

[1] On top of hill east of Burke station a few striæ bearing S. 72° E.–S. 108° W. show local divergence of the ice movement.

Striæ of the Green Bay Glacier observed by the writer and his assistants—Continued.

West of the axis of the lobe—Continued.

DANE COUNTY—continued.

Trend.

Sun Prairie Township, T. 8 N., R. 11 E., sec. 14, NW. ¼. On Trenton limestone at John Blaska's quarry.......................S. 20°-26° W.

Pleasant Spring Township, T. 6 N., R. 11 E.:

Sec. 4, southeast corner. On Trenton limestone in road....S. 25°-48° W.

Sec. 14, NE. ¼. On Trenton limestone near road; faint....S. 10° W.

Sec. 23, middle south line. On St. Peter sandstone in road..S. 15° W.

Sec. 24, NW. ¼. On Trenton limestone in gully............S. 0°-8° W.

Sec. 28, NW. ¼. On Lower Magnesian limestone at H. O. Hogan's quarry.............S. 23°-25° W.

Dunkirk Township, T. 5 N., R. 11 E., sec. 12, SE. ¼. On Trenton limestone at Ole Wethal's quarry.S. 37° W.

Medina Township, T. 8 N., R. 12 E., sec. 6, SW. ¼. On Lower Magnesian limestone in railroad cut 1 mile west of Deanville...........S. 25°-27° W.

Albion Township, T. 5 N., R. 12 E., sec. 17, SE. ¼. On Trenton limestone, in bottom of Mr. Lawton's cellar............................S. 25° W.

JEFFERSON COUNTY.

Lake Mills Township, T. 7 N., R. 13 E., sec. 33, SE. ¼. On Trenton limestone at Gus Schultz's quarry.S. 7° W.

Oakland Township, T. 6 N., R. 13 E., sec. 27, SE. ¼. On Galena dolomite in gully beside road.........S. 38° W.

Sumner Township, T. 5 N., R. 13 E., sec. 18, NE. ¼. On Trenton limestone in bottom of D. Pierce's cellar, 40 rods east of schoolhouse [1].S. 49°-64° W.

Harmony Township, T. 3 N., R. 13 E., sec. 2 east line. On Galena dolomite in bottom of E. P. Smith's cellar....................S. 20°-27° W.

Milford Township, T. 7 N., R. 14 E., sec. 6, SW. ¼. On Trenton limestone at R. Hooper's quarry [1]....S. 42°-46° W.

Aztalan Township, T. 7 N., R. 14 E.:

Sec. 20, SW. ¼. On Trenton limestone in railway cut [1]...S. 40°-44° W.

Sec. 20, SE. ¼. On Trenton limestone at quarry near river bank [1]......................S. 35°-45° W.

[1] These southwesterly trending striæ were cited on p. 163 as possibly due to the Illinoian or early Wisconsin invasion.

Striæ of the Green Bay Glacier observed by the writer and his assistants—Continued.

East of the axis of the lobe.

JEFFERSON COUNTY—continued.

Trend.

Koshkonong Township, T. 5 N., R. 14 E.:

Sec. 10, SE. ¼. On Trenton limestone at Stephen Kemp's lower quarry................S. 8°-38° W.

Sec. 10, SE. ¼. On Galena dolomite at Stephen Kemp's upper quarry......................S. 11°-14° W.

Sec. 12, SE. ¼. On Trenton limestone near Martin Schoellkopf's house...............S. 24°-29° W.

Cold Spring Township, T. 5 N., R. 15 E., sec. 32, NW. ¼. On Galena dolomite in basement of F. G. Blanke's barn....................S. 8°-13° W.

ROCK COUNTY.

Lima Township, T. 4 N., R. 14 E.:

Sec. 1, north line on Galena dolomite in road west of creek....S. 6°-27° W.

Sec. 11, NW. ¼. On Galena dolomite on F. G. Fehly's land.........................S. 12° W.

DODGE COUNTY.

Lomira Township, T. 13 N., R. 17 E.:

Sec. 14, SE. ¼. On Niagara dolomite at small quarry.....S. 10°-15° W.

Sec. 30, SE. ¼. On Niagara dolomite at quarry near Chicago, Milwaukee & St. Paul Ry.........................S. 6° W.

Theresa Township, T. 12 N., R. 17 E., sec. 33, SW. ¼. On Niagara dolomite.......................S. 20° E.

WASHINGTON COUNTY.

Addison Township, T. 11 N., R. 18 E., sec. 20, SE. ¼. On Niagara dolomite in creek valley ....S. 40° E.

FOND DU LAC COUNTY.

Fond du Lac City, third ward. On Galena dolomite at Moore's old quarry........... ....S. 23° W.

Byron Township, T. 14 N., R. 17 E.:

Sec. 10, NE. ¼. On Niagara dolomite at old Sylvester quarry, east of road..........S. 4°-8° W., S. 5°-12° E., main set later? S. 57° E., older.

Sec. 10. On Niagara dolomite in road just south of Middle..S. 8° W.

Sec. 11, east line SE. ¼. On Niagara dolomite in road......S. 9°-13° E.

Sec. 12, middle east line. On Niagara dolomite in road......S. 27° E.

Striæ of the Green Bay Glacier observed by the writer and his assistants—Continued.

East of the axis of the lobe—Continued.

FOND DU LAC COUNTY—continued.

Trend.

Byron Township, T. 14 N., R. 17 E.—Continued.
- Sec. 12, NE. ¼. On Niagara dolomite at Christ Geiger's quarry....S. 44°–49° E.
- Sec. 19, south line, SE. ¼. On Niagara dolomite near road...S. 0°–20° W.
- Sec. 19, south line, SE. ¼. On Niagara dolomite in road....S. 8° E.–S. 10° W.

Calumet Township, T. 16 N., R. 18 E., sec. 1, SE. ¼. On Niagara dolomite in creek bed at Johnsburgh.S. 3° E.

Taycheedah Township, T. 16 N., R. 18 E.:
- Sec. 9, east line, NE. ¼. On Niagara dolomite beside road.S. 4° W., later. S. 10°–22° E., earlier?
- Sec. 10 middle south line. On Niagara dolomite in road.....S. 12° E.
- Sec. 11, middle south line. On Niagara dolomite in road.....S. 22° E.
- Sec. 16, east line, NE. ¼. On Niagara dolomite in road.....S. 18°–25° E.
- Sec. 32, NW. ¼. On Niagara dolomite at quarry east of Peebles station....S. 3°–12° W., later? S. 21°–26° E., earlier?

Empire Township, T. 15 N., R. 18 E., sec. 19, NE. ¼. On Niagara dolomite in Rienzi cemetery.....S. 7°–13° E.

Ashford Township, T. 13 N., R. 18 E., sec. 23, SE. ¼. On Niagara dolomite at Ulrich Legler's at Elmore....S. 34°–54° E.

Eden Township, T. 14 N., R. 18 E., sec. 7, NE. ¼. On Niagara dolomite at Nast Bros.? quarry at Marblehead....S. 6°–9° E., earlier? S. 32°–48° E., later?

CALUMET COUNTY.

Brothertown Township:
- Lot 152, east line. On Niagara dolomite in road....S. 6°–10° E.
- Lot 22, east line. On Niagara dolomite in road....S. 25°–27° E.

Charlestown Township, T. 18 N., R. 20 E.:
- Sec. 28, north line, NE. ¼. On Niagara dolomite in road.....S. 22°–40° E.
- Sec. 28, SW. ¼. On Niagara dolomite at Union Lime Co.'s quarry....S. 23°–33° E.

New Holstein Township, T. 17 N., R. 20 E., sec. 4. On Niagara dolomite in road south of middle..S. 34° E.

Striæ of the Green Bay Glacier observed by geologists other than the writer and his assistants.

WINNEBAGO COUNTY.

Nepeuskun Township, T. 17 N., R. 14 E.:
- Sec. 4, near middle south line..S. 94° W.[1]
- Sec. 15, NW. ¼....S. 87° W.[1]
- Sec. 15, near center....S. 84° W.[1]

FOND DU LAC COUNTY.

Ripon Township, T. 16 N., R. 14 E., sec. 19....S. 82° W.[1]

Metomen Township, T. 15 N., R. 14 E., sec. 1....S. 45° W.[1]

GREEN LAKE COUNTY.

Green Lake Township, T. 15 N., R. 13 E.:
- Sec. 3....Due W.[1]
- Sec. 36....S. 45° W.[1]

DODGE COUNTY.

Trenton Township, McFarland's quarry (loc.?)....S. 50° W.[1]

Westford Township, T. 12 N., R. 13 E., sec. 19, middle, SE. ¼ (loc.?)..First set S. 24° W.; second set S. 46° W.[1]

Calamus Township, T. 11 N., R. 13 E., sec. 18, near center....S. 36° W.[1]

Portland Township, T. 9 N., R. 13 E., sec. 35, SE. ¼ (loc.?)....S. 30° W.[1]

Beaver Dam Township, sec. 20 (loc.?)....Due south.[2]

COLUMBIA COUNTY.

Lodi Township, T. 10 N., R. 8 E., sec. 23, SE. ¼. On Lower Magnesian limestone....([3]).

Caledonia Township, T. 12 N., R. 8 E., sec. 26, NE. ¼. On Baraboo quartzite....S. 85° W.[3]

SAUK COUNTY.

Greenfield Township, T. 12 N., R. 7 E., sec. 26, NW. ¼. On Baraboo quartzite....S. 85° W.[3]

DANE COUNTY.

Springfield Township, T. 8 N., R. 8 E.:
- Sec. 14, SE. ¼. On Lower Magnesian limestone....S. 73° W.[3]
- Sec. 15, NE. ¼. On Lower Magnesian limestone....S. 81° W.[3]

Blooming Grove Township, T. 7 N., R. 10 E., sec. 17, NW. ¼ (loc.?)..S. 47° W.[3]

Christiana Township, T. 6 N., R. 12 E., sec. 35, NW. ¼....S. 5° W.[3]

Albion Township, T. 5 N., R. 12 E., sec. 14, SW. ¼....S. 35° E.[3]

[1] Geology of Wisconsin, vol. 2, p. 202, 1877. [2] Idem, p. 201. [3] Idem, p. 626.

Striæ of the Green Bay Glacier observed by geologists other than the writer and his assistants—Continued.

DANE COUNTY—continued.

Dunn Township, T. 6 N., R. 10 E.:
- Sec. 8, NW. ¼. On Cambrian sandstone in gully..........S. 42° W.[1]
- Sec. 21, middle south line. On Cambrian sandstone in road..S. 16° W.[1]
- Sec. 23, near southwest corner. On Cambrian sandstone in road........................S. 10° E.[1]

JEFFERSON COUNTY.

Milford Township, T. 8 N., R. 14 E., sec. 33, SW. ¼................S. 30° W.[2]
Koshkonong Prairie (loc.?).........S. 7° E.[3]
Fulton Township, T. 4 N., R. 12 E., sec. 12, NE. ¼................S. 13° W.[3]

ROCK COUNTY.

Harmony Township, T. 3 N., R. 13 E., near line between secs. 1 and 2. In D. Smith's cellar.....S. 20°–27° W.[4]

WALWORTH COUNTY.

Whitewater Township, T. 4 N., R. 15 E.:
- Sec. 8 or 9 (?). Near Kinney's.S. 7° E.[2]
- South of Cravath Lake.......S. 12° W.[2]

FOND DU LAC COUNTY.

Fond du Lac City, third ward, Moore's quarry..................S. 15° W.[2]
Taycheedah (loc.?).................S. 15° W.[2]
Taycheedah Township, T. 16 N., R. 18 E., sec. 29, SW. ¼ SE. ¼.......S. 10° E.[2]
Empire [Taycheedah] Township, T. 15 N., R. 18 E., sec. 5, NW. ¼....S. 18° E.[2]
Ashford Township, T. 13 N., R. 18 E.:
- Sec. 11, NE. ¼. On Niagara dolomite in railway cut.........S. 59° E.[2]
- Elmore, sec. 26, NE. ¼........S. 44° E.[2]

Marshfield Township, T. 16 N., R. 19 E., sec. 30, SW. ¼. At J. Steffers's quarry (loc.?)................S. 28° E.[2]

WAUKESHA COUNTY.

Delafield Township, T. 7 N., R. 18 E., sec. 20, SE. ¼.................S. 116° W. [or S. 74° E.][5]

[1] F. T. Thwaites.
[2] Geology of Wisconsin, vol. 2, p. 202, 1877.
[3] Idem, p. 201.
[4] Frank Leverett.
[5] Cited in Geology of Wisconsin, vol. 2, p. 201, as striæ of Lake Michigan Glacier, but the outcrop is west of the main interlobate morainal ridge and the striæ appear to the present writer to pertain to the Green Bay Glacier.

Striæ of the Lake Michigan Glacier observed by the writer and his assistants.

SHEBOYGAN COUNTY.

Sheboygan Township, T. 15 N., R. 23 E.:
- Sec. 7, NW. ¼. On Niagara dolomite, west bank of Pigeon River........................S. 14°–22° W.
- Sec. 9, SE. ¼. On Niagara dolomite at Sheboygan Lime Co.'s quarry, on Pigeon River.....S. 53°–58° W.
- Sheboygan. On Niagara dolomite, at lake shore, Light House Point.................S. 50°–82° W., earlier. S. 12°–14° W., later.

OZAUKEE COUNTY.

Belgium Township:
- T. 12 N., R. 23 E., sec. 19. On Milwaukee formation at Northwestern Stone Co.'s quarry, on lake shore...................S. 48°–75° W.
- T. 12 N., R. 22 E., sec. 36, SE. ¼. On Milwaukee formation on lake shore....................S. 79°–89° W.

Port Washington Township, T. 11 N., R. 22 E.:
- Sec. 9, NW. ¼. On Niagara dolomite at Druecker's quarry...S. 91°–98° W.
- Sec. 29, NE. ¼. On Niagara dolomite in creek bed, ¾ mile northwest of Port Washington.S. 86°–91° W.

Grafton Township, T. 10 N., R. 21 E.:
- Sec. 13, SE. ¼. On Niagara dolomite beside road............S. 84°–90° W.
- Sec. 24, SE. ¼. On Niagara dolomite, in west bank of Milwaukee River at Grafton........S. 46°–48° W. S. 83°–111° W.

WASHINGTON COUNTY.

Germantown Township, T. 9 N., R. 20 E.:
- Sec. 22, NE. ¼. On Niagara dolomite at Nehs Lime Co.'s quarry at Germantown......S. 85°–87° W.
- Sec. 35, SE. ¼. On Niagara dolomite at quarry near Jacob Schmidt's place.............S. 80° W.

WAUKESHA COUNTY.

Lisbon Township, T. 8 N., R. 19 E.:
- Sec. 21, NE. ¼. On Niagara dolomite in Chicago, Milwaukee & St. Paul Ry. cut..........S. 128° W.
- Sec. 34, near middle. On Niagara dolomite................S. 90°–104° W.
- Sec. 35, NW. ¼. On Niagara dolomite at Potter's quarry...S. 88°–96° W.

Striæ of the Lake Michigan Glacier observed by the writer and his assistants—Continued.

WAUKESHA COUNTY—continued.

Pewaukee Township, T. 7 N., R. 19 E.:
- Sec. 9, NE. ¼. On Niagara dolomite at quarry at Pewaukee. S. 85°–90° W.
- Sec. 26, SE. ¼. On Niagara dolomite at quarry 2 miles north of Waukesha. S. 66°–76° W.
- Sec. 26, SE. ¼, 40 rods south of above. S. 81° W.
- Sec. 33, SW. ¼. On Niagara dolomite at Siegel's old quarry. S. 72°–73° W.
- Sec. 35, NW. ¼. On Niagara dolomite at Hadfield's quarry, west side Fox River. S. 57°–74° W. S. 75°–81° W.
- Sec. 35, NE. ¼. On Niagara dolomite at Waukesha Stone Co.'s quarry, east side Fox River. S. 30° W.

Waukesha Township, T. 6 N., R. 19 E., Waukesha. On Niagara dolomite near Carroll College. S. 75° W.

Genesee Township, T. 6 N., R. 18 E., sec. 26, NE. ¼. On Niagara dolomite. S. 30°–94° W.

Menomonee Township, T. 8 N., R. 20 E.:
- Sec. 3, SE. ¼. On Niagara dolomite at Menomonee Falls. S. 73°–95° W.
- Sec. 17, SW. ¼. On Niagara dolomite at Lake Shore Stone Co's. quarry. S. 92°–103° W.
- Sec. 18, NE. ¼. On Niagara dolomite at Lake Shore Stone Co.'s quarry. S. 96°–112° W.

MILWAUKEE COUNTY.

Granville Township, T. 8 N., R. 21 E., sec. 26, SW. ¼. On Niagara dolomite at quarry of F. A. Zautcke's estate. S. 20°–48° W.

Wauwatosa Township, T. 7 N., R. 21 E.:
- Sec. 26, N. ½. On Niagara dolomite at A. F. & L. Manegold's quarry in Menomonee River valley west of Milwaukee. S. 56°–72° W.
- On Niagara dolomite at Story Bros.' quarry, southwest of Grand Avenue viaduct. S. 44°–71° W.

RACINE COUNTY.

Mount Pleasant Township, T. 3 N., R. 23 E., sec. 6, On Niagara dolomite at Horlick's quarry on Root River, 2 miles northwest of Racine. S. 83°–93° W.

Striæ of the Lake Michigan Glacier observed by geologists other than the writer and his assistants.

SHEBOYGAN COUNTY.

Sheboygan Falls Township, T. 15 N., R. 20 E.:
- Sheboygan Falls[1]. S. 55° W.; Due W.; Due S.
- Do. S. 64° W.[2]
- Sec. 16, Howard's quarry (loc.?) S. 78° W.[2]

MILWAUKEE COUNTY.

Milwaukee, fourth ward, Moody's quarry, north slope of Menomonee Valley at Twenty-seventh Street. S. 86° W.[2]

WALWORTH COUNTY.

East Troy Township, T. 4 N., R. 18 E., sec. 11, SW. ¼. At Castleman's old quarry, east of Potter Lake; obscure. S. 45°–50° W.[3]

RELATIONS OF THE ICE TO BEDROCK.

RECORDS ON THE ROCK.

The rock surface at the various exposures within the glaciated area affords interesting evidence of the action of the moving ice. At many places where the upper layer of the rock was sufficiently firm and indurated to resist the push and drag of the glacier and was also of such texture as to receive and retain the planing, polishing, and striating effects of moving ice, shod with rock fragments and supplied with fine abrasive material and polishing powder, the effects of glaciation are well exhibited. These effects are only observed, however, where the rock surface has but recently been stripped of a protecting layer of drift, either by wave or stream action, or by artificial excavation as in quarries, cellars, wells, and wagon road and railway cuts. Where such a protecting mantle is absent, or where it is thin and porous, the solvent effect by meteoric waters and other agencies of weathering has generally removed all traces of ice action by etching and roughening the surface.

Of the sedimentary rocks the limestones, where protected, show best the effects of glaciation. A few striæ have been observed on the St. Peter, Madison, and older Cambrian

[1] Whittlesey, Charles, On the ice movements of the glacial era in the valley of the St. Lawrence: Am. Assoc. Adv. Sci. Proc., vol. 15, pp. 43-54, 1867.
[2] Geology of Wisconsin, vol. 2, p. 201, 1877.
[3] Idem, p. 204.

sandstones, but at most places crumbling has effaced whatever signs of glacial action these rocks may have borne. The "Cincinnati" shale, with the exception of certain included hard layers, is too soft and friable to receive and retain striæ; moreover, it is rarely exposed within the area under discussion and then usually below a protecting cap of dolomite. Shaly layers of the Trenton and the rather soft impure limestone of the Milwaukee formation of the Devonian rarely show striæ.

PLANATION, POLISHING, AND STRIATION.

The effects of glaciation are finely preserved at many exposures of the Ordovician and Silurian limestones where the protecting mantle of drift has been but recently removed. In most places the limestone strata are nearly flat lying, so that much of the observed effects of the glacial action are on surfaces nearly coinciding with the bedding planes. Such surfaces, especially where the rock is dense and even textured, are smoothed and polished, with a sort of case-hardened finish on the surface that in many places well reflects the sunlight. Rarely grooves are found fluting the rock surfaces, but generally the striæ are rather clean cut, fine lines of graving, in many places microscopic. When water attacks such surfaces it widens and deepens these scratches and other irregularities of the surface, until in some places gashlike depressions are developed. Roughened patches spread until the intervening polished surfaces are removed. Most of the unprotected rock surfaces have long since been so roughened, and it is rare to find any preglacial residual material overlying the rock within the limits of the later drift.

One of the best examples of planed, polished, and striated surfaces of flat-lying limestone observed was at Randall's quarry at Waupun. On several streets in the city the walks are largely composed of these finely glaciated flagstones, and they are said to have been used in the construction of cells in the first penitentiary building.

Irregularities in such glaciated rock surfaces often afford conclusive evidence as to which way the ice was moving. The parts of ledges facing the ice advance are commonly smoothed and striated, while those facing toward the lee may be left unabraded. At Manegold's quarry, west of Milwaukee, a surface exposed at the time of the writer's visit was interrupted by slight vertical offsets in the upper stratum of limestone exposing faces about 2 inches high and 15 feet long transverse to the direction of the ice movement. The east faces of these offsets were well rounded with striæ running up over them from the lower to the higher level and the west faces were abrupt and not glaciated, thus indicating clearly the westerly direction of the ice movement.

KNOBS AND TRAILS.

The glaciation of limestone set with chert nodules may produce the phenomena of "knobs and trails."[1] This is particularly well illustrated in the area of the Illinoian drift 3 miles southwest of Janesville, in the NE. ¼ sec. 16, T. 2 N., R. 12 E. (Rock Township). (See Pl. XXI, *A*.) It is also well exhibited by a low-domed surface of Lower Magnesian limestone exposed in the road in the NE. ¼ sec. 9, T. 13 N., R. 12 E., Randolph Township, Columbia County, where the limestone, being worn down by the abrasive action of the ice, left chert nodules projecting a fraction of an inch with slight ridges of limestone trailing to leeward, showing that the rock-shod ice did not settle immediately in the lee of the small obstruction.

ADVANCE CONES.

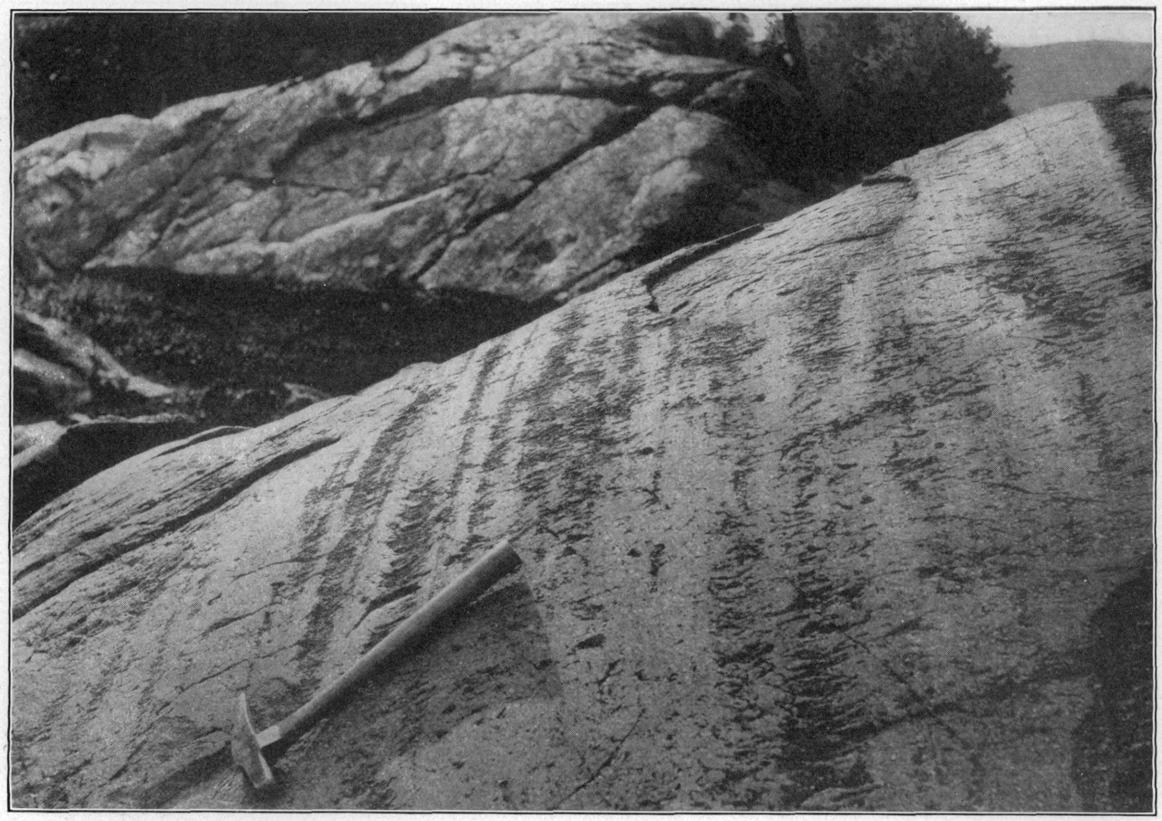
A rare phenomenon (fig. 8) on the glaciated surface of the limestone at Pewaukee, Wis., is described by Chamberlin[2] under the title "Advance cones" as "consisting of a half cone in bas-relief on the face of the glaciated rock, the apex of which is directed toward the point of origin of motion and the base of which is unworn, as is also a limited space in the rear."[2]

FIGURE 8.—"Advance cone" on glaciated limestone at Pelton's quarry, Pewaukee, Wis. After T. C. Chamberlin.

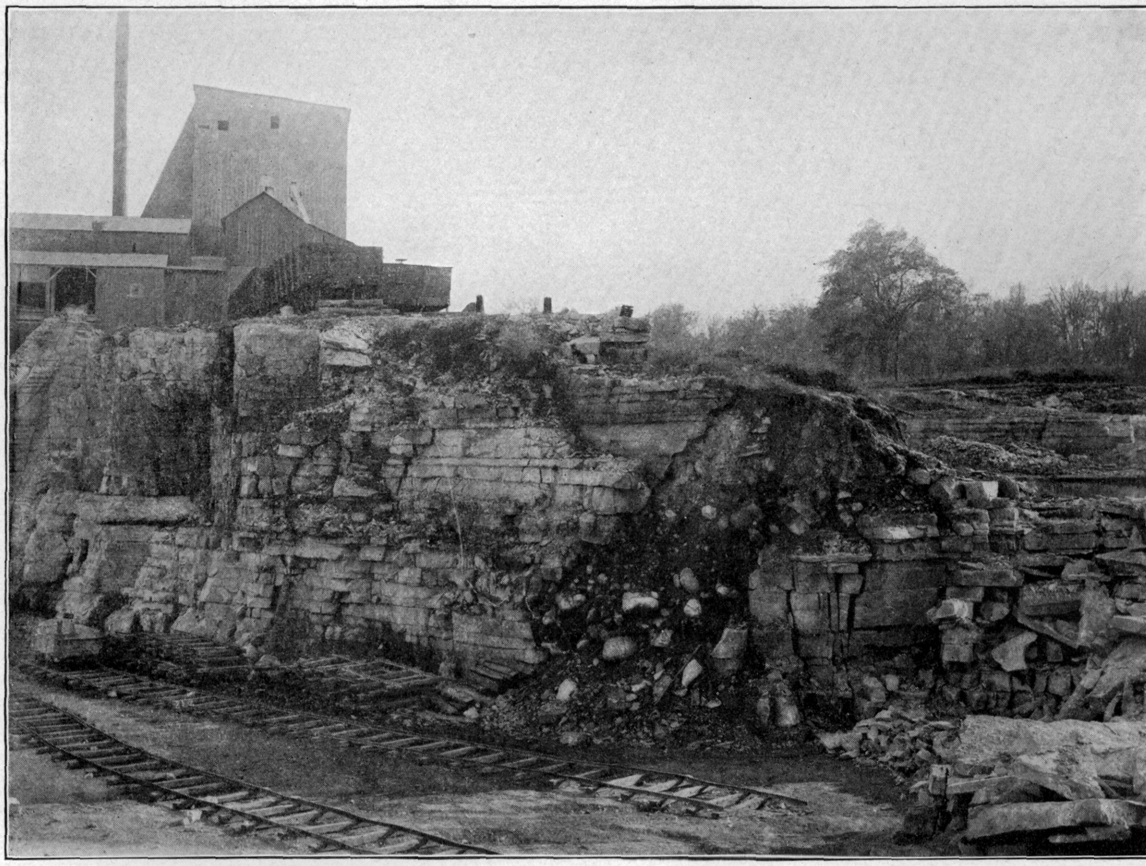
The parallel lines (see fig. 8) represent the striæ. The base of the cone is not striated and

[1] Chamberlin, T. C., The rock scorings of the great ice invasions: U. S. Geol. Survey Seventh Ann. Rept., pp. 244-245, 1888.
[2] Idem, p. 245. Also, Geology of Wisconsin, vol. 2, p. 200, 1877.

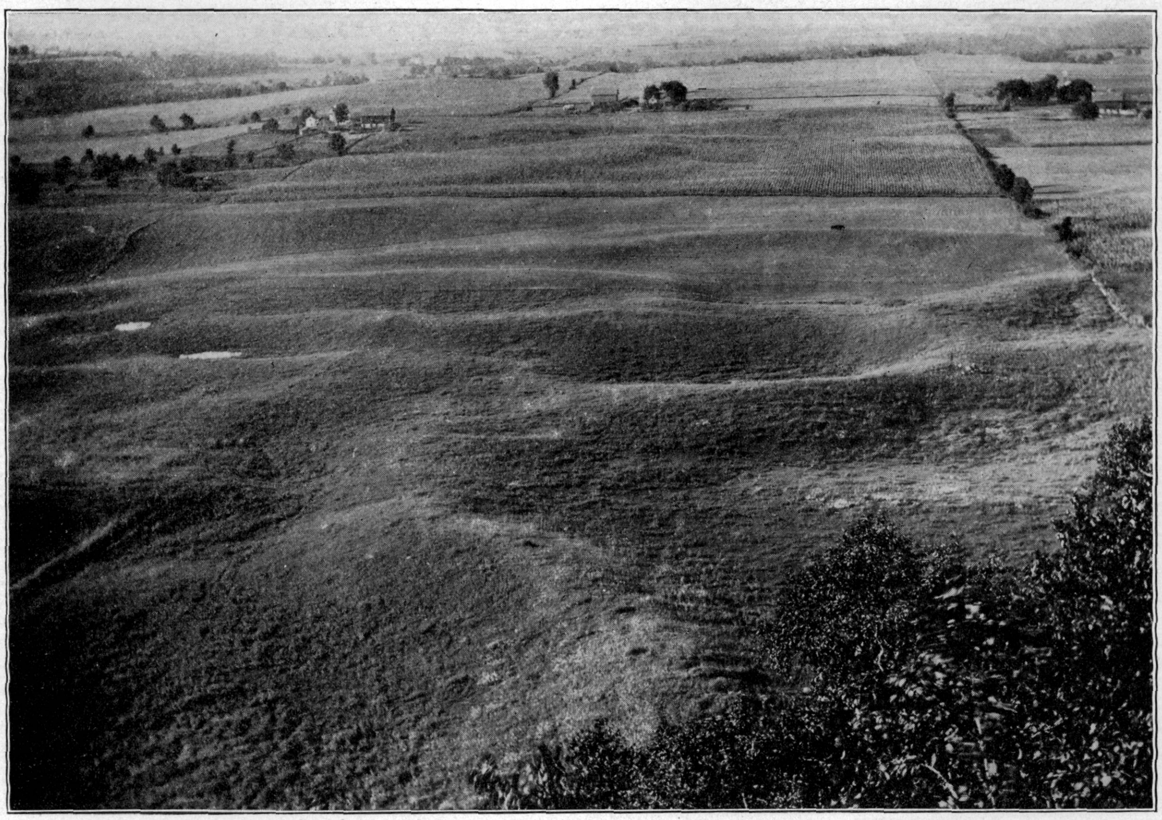
A. GLACIATED LIMESTONE IN BED OF CREEK 3 MILES SOUTHWEST OF JANESVILLE, WIS., SHOWING HALF CONES FORMED IN LEE OF CHERT NODULES.



B. GLACIALLY SMOOTHED AND STRIATED SURFACE OF RHYOLITE LEDGE A MILE SOUTHWEST OF MARQUETTE, GREEN LAKE COUNTY, WIS., SHOWING CRESCENTIC "CHATTER MARKS."



A. GIANT POTHOLE IN NIAGARA DOLOMITE FILLED WITH GLACIAL DRIFT AT LAKE SHORE STONE CO.'S QUARRY, LANNON, WAUKESHA COUNTY, WIS.



B. SURFACE OF MORAINAL DRIFT NORTH OF BLACKHAWK BLUFF IN THE WISCONSIN RIVER VALLEY A MILE NORTHEAST OF PRAIRIE DU SAC, WIS.

the adjacent surface of the rock is rough but becomes gradually smoothed, and at length merges into the polished plane surface, demonstrating the direction of glacial movement.

OBLIQUE AND CROSSING STRIÆ.

Striæ having a trend oblique to the direction of the last ice movement have been cited (p. 163) as possibly due to an earlier ice advance. The preservation of two sets in one place, an earlier and a later crossing set, on the same rock surface shows that a very slight amount of abrasion was here accomplished by the later glacier. One of the most interesting occurrences known was observed by the writer at an exposure of Niagara dolomite on the beach below the lighthouse at Sheboygan.[1] The surface of the dolomite rises gradually above the water level and has been stripped of its drift covering by wave action, but the effects of the glacial abrasion have not been removed. The surface is beautifully smoothed and striated. The striæ of the main set range from S. 50° to 82° W. At the north side of the exposure, especially, these are crossed by what appears to be a later set ranging S. 12° to 14° W. In places the earlier set is worn away and only the later set is seen; elsewhere both sets are found crossing on the same surface; and in still other parts, where there are slight inequalities of the surface an inch or less in relief, the later set is found alone on the higher parts and the earlier set alone on the bottoms of the shallow depressions. In the latter places a very thin veneer of drift may have preserved the earlier striæ.

The formation of the two sets of striæ may have been separated by a considerable interval of deglaciation, but in many cases (if not here) the variation in direction may be due to slight shifts in the basal currents of the ice. Rarely or never are the striæ on any given rock surfaces found to be absolutely parallel. As may be seen from the bearings cited (see pp. 147–203) they may diverge 10° to 30° or more at any given place.

At several places along the crest of the Niagara escarpment south and east of Fond du Lac two sets of striæ were noted, an earlier and more southeasterly bearing set crossed by a later and more southerly bearing set. The earlier set is thought to have been formed when the Green Bay Glacier was thickest and had its maximum extension. At this time the controlling effect of the Niagara escarpment was least, and the ice freely overtopped the bluff and radiated southeastward to the marginal line along which the Green Bay ice front met the opposing front of the Lake Michigan glacier and formed the Kettle interlobate moraine. Later, when the glacier had become so thin and so short that it extended only to one of the inner marginal moraines, the north-south trending Niagara escarpment would have had greater influence on the direction of the ice flow and have diverted it to a more southerly direction at the several places where the earlier set of striæ were inscribed. It is of interest to note that the axes of the neighboring drumlins, instead of radiating toward the interlobate moraine, are more nearly parallel to the southerly bearing striæ of the later set, as though they themselves were molded during the later stage of ice advance.

KNOBS AND ROUNDED SURFACES.

The crests of most of the knobs of crystalline rocks within the area have been more or less smoothly rounded, polished, and striated. Some of the rock surfaces have been sufficiently roughened by weathering or have been exfoliated sufficiently to remove the evidence of glaciation, but others still preserved them. It is probable that the generally rounded form of these knobs is of preglacial if not pre-Cambrian origin, so that no great amount of abrasion is to be referred to glacial action, which was probably confined very largely to removing of loose or partly loosened blocks by plucking, to rounding exposed edges, and to polishing and striating the rounded surfaces. For example, the crests of the rhyolite ledges in the NE. ¼ sec. 34, T. 15 N., R. 11 E. (Marquette Township), are smoothed, rounded, polished, and striated, and show small crescentic gougings, convex toward the east, known as chatter marks.[2] (See Pl. XXI, *B*.) There is also a divergence of striæ about the crest of this knob, striæ at the top of the north slope bearing S. 123° W. and at the top of the south slope S. 94° W.

[1] A portion of this glaciated surface is illustrated by Charles Whittlesey, on the fresh-water glacial drift of the northwestern States: Smithsonian Contr. Knowledge, vol. 15, art. 2, fig. 4, p. 7, 1867.

[2] U. S. Geol. Survey Seventh Ann. Rept., pp. 218–219, 1888.

ROCHES MOUTONNÉES.

Rounded surfaces of ledges, known as sheepbacks or roches moutonnées, are well developed on the quartzite of the island ledge in the NW. ¼ sec. 27, T. 9 N., R. 13 E. (Portland Township). The bedding of the quartzite dips 27° N. 130° E. The movement of the ice, being nearly parallel to the strike (S. 20°–36° W.), rounded and smoothed the upturned edges (Pl. VIII, *B*, p. 64) and polished the surfaces. The polish, however, has been removed for the most part by a slight roughening of the surface due to exposure to the weather. Chatter marks, 8 inches in width, convex toward the northeast, were seen on some of the northerly sloping surfaces. These surfaces are also pitted in places by shallow pot holes, one of which is 19 inches in diameter and 6 to 7 inches deep, that may possibly have been worn by water plunging down crevasses or moulins in the overlying glacier. It is hardly probable that they were developed since the melting of the ice by stream action in the positions where they were found. They may, however, have been formed much earlier, possibly by Tertiary action like those on the bluffs at Devils Lake (p. 100), or they may be even of Paleozoic or pre-Paleozoic age.

Freshly stripped surfaces of quartzite of the quarry ledge in sec. 33, Portland Township, are smoothly rounded and striated and so polished as to glisten in the sunlight and afford only precarious footing.

The roche moutonnée form is also well developed in places on the Baraboo quartzite, especially on the isolated ledge 2½ miles northeast of Baraboo at the middle of the north line of sec. 32, T. 12 N., R. 7 E. (Greenfield Township).

EFFECTS OF ICE PUSH.

At several places the uppermost rock strata are disturbed as though they had been pushed out of their original positions by the direct action of the advancing ice. One instance of such phenomena was observed (fig. 9) at Sholts's small quarry in Trenton limestone, about 2 miles southeast of Oregon, in the NE. ¼ sec. 25, T. 5 N., R. 9 E. (Oregon Township), where the upper part of the limestone is in thin layers 2 to 4 inches thick. At the east end of the south face of the quarry, as exposed at the time of the writer's visit, the upper layers were bent upward as though crowded by push to the west or southwest. This was undoubtedly due to the thrust of the glacial ice as it ascended the east slope of the ledge.

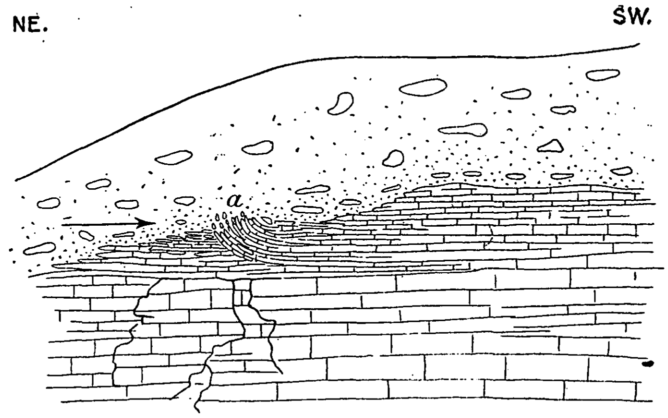


FIGURE 9.—Effect of glacial ice push; thin, upturned beds of limestone (*a*) in small quarry on Sholts estate, 2 miles south of Oregon, Wis.

About 8 miles southeast of the above locality and 4 miles northeast of Evansville at Miller's small quarry in Trenton limestone in the NE. ¼ sec. 12, T. 4 N., R. 10 E. (Union Township) further evidence of ice push was noted. The quarry face exposed, when seen by the writer, extended about S. 25° W., or nearly parallel to the direction of the ice movement. At the northeast end of this face (fig. 10) the layers of rock were broken up and crowded into an anticlinal fold 6 or 7 feet high. The limestone layers were not bent but broken, with the blocks disposed in curving lines over a well-defined fold. The dips on the north limb were about 22°, but the thrust steepened the dips on the south limb to 70°. In the core of the fold the blocks were turned up on edge and somewhat overthrust. This fold was developed where the ice ascended the northeast slope of the rock surface over the edges of the strata. Overlying the disturbed and undisturbed strata is 6 to 8 feet of glacial till.

A somewhat similar instance is described by Chamberlin[1] as having been observed at Mr. Smith's [Aldrich's] quarry, 1½ miles west of Burlington in the NE. ¼ sec. 36, T. 3 N., R. 18 E.

[1] Geology of Wisconsin, vol. 2, p. 203, fig. 4, 1877

(Spring Prairie Township), near the east bank of White River.

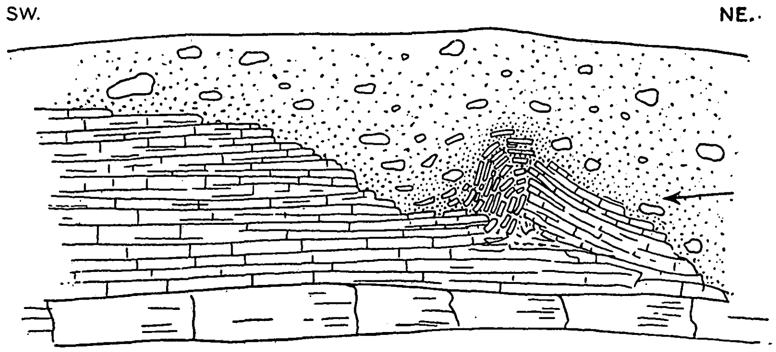


FIGURE 10.—Effect of glacial ice push on thin-bedded limestone in small quarry on Miller farm, 4 miles northeast of Evansville, Wis.

Certain conditions seen in an exposure at Hartford, Washington County, though not so plainly due to ice push, yet suggest such an agent. An excavation opened by L. Kissel & Son in a small hill in the southeastern part of Hartford for gravel exhibited the relations shown in figure 11. Niagara dolomite was exposed, rising southward at 38° and curving thence over to 10° or 12°. The rock was bedded in layers (*a*), mostly not much cracked or broken, the thickest being 16 inches. Just above the thickest bed, at *e*, was a layer of red to brownish shaly, ocherous material, much of which was mixed in the drift, especially at the south end. At *c* a large pocket of clayey till and bowlders extended down to the bottom of the section, as the till did also at the north and south ends of the section at *d–d*. At the north or stoss end of the hill the drift was crowded into the crevices in the rock, breaking up the layers at the top and sides; and over *b* the upper part of the dolo-

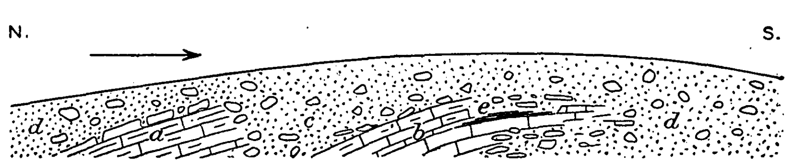


FIGURE 11.—Effect of glacial ice push (?) on dolomite in southeastern part of Hartford, Wis.

mite was also much broken and intermingled with the drift. The relations show that the crowding in of the drift was due to ice push and suggest that the tilting of the dolomite strata may also have been due to the same cause.

At the old quarry in the third ward at Fond du Lac, the Galena dolomite is disposed in a peculiar broken anticline or gable. (See fig. 12.) On the north side of the crest the rock floor dips 15° N. 35° E., and on the south 10° S. 22° W., flattening within 2 rods to nearly horizontal, the heavy bed being broken along a line striking S. 68° E. to N. 55° W. This fold or gable looks unnatural, as though the rock on the north side of the crest had broken off or tipped over and that on the south had been forced up at the edge. The direction of glacial movement at this point, as shown by striæ on the surface of the uppermost layer, was S. 23° W., or nearly at right angles to the strike of the gable crack. About seven-eighths of a mile northeast of this quarry the city well was drilled to a depth of 106 feet before it reached

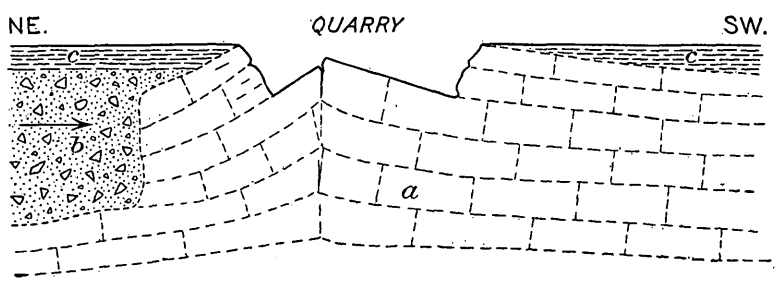


FIGURE 12.—Effect of glacial ice push (?) on dolomite at old quarry in third ward, Fond du Lac, Wis. *a*, Galena dolomite; *b*, glacial drift; *c*, lacustrine clay.

rock. The surface of the rock at the well is thus about 110 feet lower than that at the quarry. This suggests the possibility that in preglacial time the rock exposed in the quarry formed the crest of a rather steep slope or bluff and that a mass of rock, broken away under the force of gravity, had crept or tilted slightly away from the main ledge. When the glaciers advanced over this rising slope the loosened mass may have been crowded back against the ledge in a tilted position and may have forced up the edges of the strata of the ledge into the position they now occupy.

Two miles west of Liberty Bluff station, in the SW. ¼ sec. 3, T. 17 N., R. 8 E. (Springfield Township), an abrupt isolated bluff of sandstone with a partial capping of Lower Magnesian limestone forms one of the most northwesterly of the erosion remnant outliers of this rock formation. This bluff is known as "Lime Bluff" from the occurrence in the lower slope at its west end of limestone, which was quarried and burned for lime some years ago. The relations of the limestone exposed in the quarry are interesting, for they indicate a displacement possibly due to the push of the glacier which overrode the bluff from east to west. The highest part of the crest of the bluff is about 1,150 feet above the sea (by barometer), of which the limestone in place at the east end of the crest constitutes not more than 20 feet or so. The west end of the crest above the quarry reaches 1,090 to 1,100 feet above sea level, or not so high as the base of the limestone. Yet in the lower west slope from 1,000 to 1,040 feet above the sea Lower Magnesian limestone is exposed. The rock has evidently been displaced, for the heavy layers dip into the face of the bluff at high and divers angles (fig. 13). The relations suggest that the west end of the crest of the sandstone

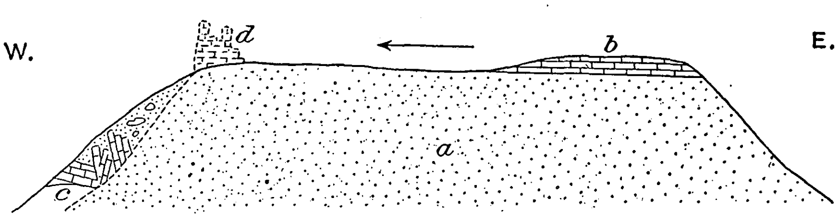


FIGURE 13.—Relations of limestone and sandstone in Lime Bluff, 2 miles west of Liberty Bluff station, Marquette County, Wis., illustrating effects of glacial ice push (?). *a*, Cambrian sandstone; *b*, Lower Magnesian limestone in place; *c*, displaced Lower Magnesian limestone exposed in quarry; *d*, supposed original position of limestone.

bluff was capped in preglacial time by a ledge or tower remnant of the limestone and that the push of the glacier advancing from the east shoved the mass of limestone off the crest so that it slid down the west end, the layers tipping into divergent positions against the slope. The continued advance of the ice mantled the whole with a thin coating of drift, smoothing and rounding the slopes so as to obscure the displaced ledge of limestone. It is possible that this mass slid down before the earliest glacial advance reached this bluff.

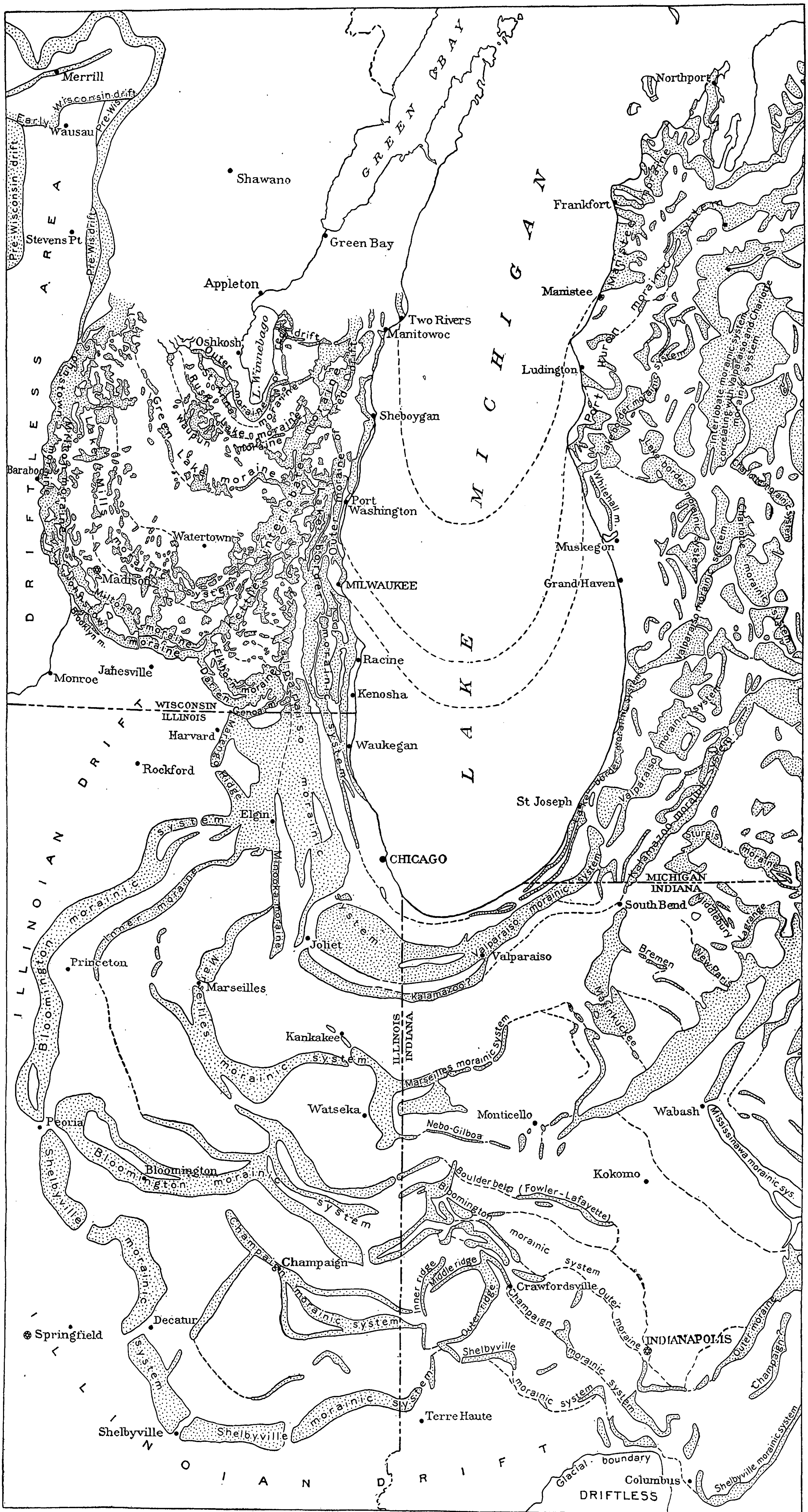
PLUCKING.

The best exhibition of the conditions favoring the plucking of blocks from a rock ledge by overriding glacier ice is at the ledge of quartzite near Hubbleton in the SE. ¼ sec. 35, T. 9 N., R. 13 E. (Portland Township). The ledge, which is exposed for 50 to 75 feet north to south, rises about 15 feet above the marsh on the west. (See p. 65.) The bedding, which is plainly marked, dips at an average 27° E. The strike is about N. 90° W., or oblique to the direction of the last ice movement. The rock is closely crosscut by three sets of joints and owing to the exposure of the edges of the beds and to these abundant cross fractures the conditions were exceptionally favorable for the removal of blocks by plucking. A notable feature is the large accumulation of quartzite bowlders, mostly angular, immediately in the lee of this ledge, where they form a ridge tailing several rods to the south until they disappear in the marsh. The surface of the ledge has the appearance shown in Plate VIII, *A* (p. 64), only the corners and edges being rounded.

Stretching away to the south in the lee of this and the other quartzite ledges of the Waterloo area are broad fanlike bowlder trains extending to the limits of the ice advance. The total amount of quartzite on the surface and included in the drift within the limits of these trains is considerable. Many of the more angular blocks were doubtless derived from the ledges by plucking, others were picked up where lying loose on the surface. Much of the rounded material was probably derived from accumulations of pebbles and bowlders loosened by the disintegration of the sandstone matrix of the basal conglomerate (Pl. IX, *B*, p. 65), which doubtless once mantled all the quartzite ledges. Similar but less extensive trains of plucked or gathered bowlders extend in the lee of the several knobs or crystalline rock in Waushara, Green Lake, Marquette, and Columbia counties.

POTHOLE.

A unique and interesting feature which may be considered in this discussion of the relations of the glacier to the bedrock is a giant pothole and a channel disclosed in quarrying at the



MAP SHOWING THE RELATIONS OF THE MORAINES OF THE LAKE MICHIGAN AND GREEN BAY GLACIERS OF THE WISCONSIN STAGE OF GLACIATION.

By Frank Leverett, W. C. Alden, and Samuel Weidman.

Lake Shore Stone Co.'s quarry north of Lannon in the NE. ¼ sec. 18, T. 8 N., R. 20 E. (Menomonee Township). In 1904 the section exposed in the west face of the quarry north of the crusher (see Pl. XXII, *A*) had a height of about 27 feet and revealed a great pothole or channel inclined 45° and extending nearly to the bottom of the section with a width of 10 to 12 feet measured perpendicular to the side walls. The walls of the cavity were smoothly rounded and the depression was filled with glacial drift containing many smoothly rounded crystalline bowlders and it is said some drift copper. A large part of the walls and contents of the cavity had been removed by quarrying and the semicircular outline of the drift-filled lower part of the depression could be seen in the quarry floor. This had a diameter of 46 feet and extended to a depth which had not then been determined. The outline of the cavity in the north face of the quarry had more the form of a section of a tortuous channel, constricted at one point to 8.3 feet by a shelf-like ledge projecting from the east wall of the cavity, but widening above to 29.8 feet. The channel could then be traced about 100 paces N. 5° E. The north end where it appeared to be shallowing rapidly had previously been removed by quarrying. R. F. Bemm, superintendent, stated that excavation to a depth of 15 feet was made for the west foundation wall of the crusher without reaching rock, although the east wall stood on the exposed ledge. This shows that the channel extends for some distance southward, but its course had not been further explored. Owing to so much of the rock having been removed by quarrying and the course of the channel being so obscured, it is not possible to frame a wholly satisfactory explanation of the mode of origin of the cavity. From the solid condition of the rock and the smoothly worn walls of the cavity it is evident that in its final form, at least, its origin was not that of a cave due to decay or removal of the rock in solution. The form is that of a channel excavated by running water, which was broadened at one point by stones whirling in an eddy and excavating the great pothole seen in cross section in the quarry floor. The rock at the highest point now stands 40 feet above the quarry floor. Mr. Bemm stated that originally it rose as a ledge or cliff nearly as high as the derrick. If such was the case, the great pothole must have been immediately west of the ledge. Striæ on the rock surface show the direction of the ice movement to have ranged from S. 96° to 112° W. These conditions suggest that the pothole and channel may have been developed by glacial waters. It is possible that in overriding this small rock hill the ice was crevassed so that water plunged down in the lee of the elevation, excavating the pothole and flowing thence by the lateral channels. It may be, however, that the cavity is due to preglacial stream action. In that case, the drift filling the depression was probably deposited during one of the earlier advances.

GREEN BAY GLACIER.

JOHNSTOWN MORAINE.

GENERAL RELATIONS.

The finely developed terminal moraine which marks the limit of the Green Bay Glacier on the south and west has been designated the Johnstown moraine, from the villages of Johnstown and Johnstown Center, in eastern Rock County, which are situated near the most southerly point it reaches.[1] Its general distribution will be understood better from Plate III (in pocket) and Plate XXIII than from any detailed description. Its relations to the topography and rock formations on which it made its marginal deposit are, however, both interesting and instructive and require some detail of description. It is worth while to trace it from point to point and note these relations and its structure and composition so far as may be determined from the exposures available and from the records of wells.

Taken as a whole, the terminal moraine may be characterized as the thickened marginal portion of the drift sheet deposited by the Green Bay Glacier. Its form and relief result very largely from its thickness and its relation to the topography of the surface on which it was laid down, both of which vary greatly from point to point. Perusal of the description of the bedrock surface (pp. 105–128), and examination of Plate II (in pocket), will make clear the larger features of the early topography. It should be remembered, however, that the Green Bay Glacier of the later Wisconsin sub-

[1] Alden, W. C., The Delavan lobe of the Lake Michigan Glacier of the Wisconsin stage of glaciation and associated phenomena: U. S. Geol. Survey Prof. Paper 34, p. 35, 1904.

stage did not lay its morainal deposits directly on the uncovered, dissected topography of the preglacial rock surface. Where the later ice extended beyond the limits of the earlier glaciation and encroached on the Driftless Area this was in part the case, but, even here, as has already been pointed out (p. 192), it is probable that earlier outwash deposits partly filled the valleys. Where the later ice was less extensive than the earlier, it is probable that earlier drift not only occupied the valleys but also probably mantled the slopes and crests of the ridges to a greater or less extent. These earlier deposits, owing to meagerness of exposure or lack of exposure or to similarity in character with the later deposits, are not usually distinguishable, so that, to a certain extent, the whole thickness of the drift in the morainal belt is here considered. But the probability that a large part of it is of earlier origin should be borne in mind.

DISTRIBUTION AND TOPOGRAPHIC RELATIONS.

Walworth County.—Parting from the Darien moraine of the Delavan lobe of the Lake Michigan Glacier at the branching of the Kettle interlobate moraine in northwestern Walworth County, the Johnstown moraine lies across a narrow valley near the county line and extends thence westward along the top of a broad ridge of Galena dolomite 10 to 12 miles to the broad buried valley of the preglacial Rock River. In this part it appears as a broad ridge varying in width from three-fourths mile near Richmond to nearly 5 miles farther west. On the south it is bordered by an extensive flat outwash plain, from which its front rises 40 to 140 feet, in places sharply but generally with gentle slope, to an undulating crest line varying in altitude from 920 to 1,060 feet above sea level. In most places the inner and outer slopes are much the same, but in western Walworth County near the interlobate angle the inner face becomes abrupt with a relief of 100 feet or more. Quite large tracts of the inner half of the morainal belt have the gentle undulations of ground-moraine topography, with only occasional slight sags and swells. In the outer half the surface is somewhat rougher from the presence of gravel knolls and kettle holes, but such intricate topography as characterizes the Kettle interlobate moraine is not found here nor indeed elsewhere. From the records of wells it is known that the thickness of drift in this part of the moraine ranges from a few feet to 238, the estimated average being 62 feet.

Rock County.—In adjacent parts of Fulton, Milton, Janesville, and Harmony townships of northern Rock County the moraine lies across the preglacial valley of Rock River, here 350 to 450 feet in depth and 6 to 7 miles in width between the crests of the rock ridges beneath the moraine on either side. The moraine so nearly fills this great valley that the drift rises as a broad ridge 40 to 100 feet above the bordering outwash terrace which maintains about the same elevation as farther east. The maximum thickness of drift in this valley is probably at least 500 feet, though no wells are known to have penetrated it to greater depths than 307 feet. With the data at hand it can not be determined how much of this deposit is due to the Green Bay Glacier of the last glacial advance and how much remained of earlier drift sheets. From the data presented concerning the earlier drift sheets it is possible that not more than one-third of the average drift in the area covered by this and the other morainal belts is to be referred to later Wisconsin deposition. In this part some considerable ice blocks must have been buried, for the moraine crest, where crossed by the Chicago & Northwestern Railway, is cut by a sag, not wholly, at least, due to erosion, for its bottom includes large inclosed depressions, the deepest extending 100 feet below the level of the bordering outwash plain.

Extending southward from the vicinity of Edgerton between the ancient converging Yahara and Rock valleys is a buried rock ridge 250 to 300 feet in height. The moraine lies across the south end of this ridge and the Yahara Valley on the west, with a width of 3 to 4 miles. The moraine is here not a simple broad ridge but is rather a more or less hilly belt marked by gentle sags and swells, with some closely pitted tracts and some large depressions. Near the river there is a sharp marginal ridge 10 to 80 rods in width with south slope of 20 to 80 feet. One line of depressions above the east slope of the rock ridge constitutes a continuous sag across the moraine similar to that traversed by the railway farther east. Both sags have outlets approximately 900 feet above sea level. A third sag in the line of the

Yahara Valley must have been somewhat lower, for on the disappearance of the ice it became the outlet for the drainage of the whole southern part of the area traversed by the Green Bay Glacier.

From the ancient Yahara Valley westward to the vicinity of Evansville the glacier, after crossing the crest of a broad limestone-capped ridge that lay between the Yahara Valley and an ancient valley heading in the vicinity of Brooklyn, extended 1 to 2 miles down the southwest slope, depositing there its terminal moraine. Between Evansville and Brooklyn the moraine lies in the valley and extends across to the foot of the west slope. This relation would not be suspected from the present surface configuration but is revealed by the correlation of well records. In this part, through the towns of Porter, Union, and Rutland, the moraine varies in width from 2 to nearly 5 miles. The outer front is very distinctly marked, being bordered by a flat outwash terrace of considerable extent, from which it rises with a slope 40 to 160 feet in height. The inner margin, on the contrary, is very indefinite, the gentle sag and swell topography grading imperceptibly into the slight undulations of the ground moraine, so that in many places the boundary line must be arbitrarily placed. Within a mile of the outer margin the surface is much broken by knolls and kettles, in many places closely set and with reliefs of 20 to 50 feet, but back of this are gentle sag and swell tracts which are nearly flat or have the contours of the ground moraine. Some of the depressions probably contained small temporary lakes as the ice melted back toward the inner margin. At a few places the Trenton limestone forming the crest of the buried rock ridge is exposed at the surface. From a thin covering of a few feet at these places, the drift ranges up to 200 feet, with an estimated average of about 96 feet. In sec. 16, T. 4 N., R. 10 E. (Union Township), the Brooklyn moraine emerges from beneath the Johnstown moraine, so that a part of this thickness very probably belongs to this earlier moraine. An excellent view of the outer front of the moraine is to be had on the Chicago & North Western Railway from the vicinity of Leyden station to a point 2 miles north of Brooklyn. Through this distance the railway traverses the outwash plain which borders the outer front of the moraine.

Dane County.—Just north of Brooklyn a slight reentrant angle, about a mile deep, occurs at the head of the valley. From this angle the moraine front extends westward 2 miles across the head of the valley, then curving to the northwest it crosses the narrow rock ridge on the west, traverses a lower sandstone tract, surmounts a second limestone-capped ridge, and reaches the valley traversed by the Illinois Central Railroad. In the lower tracts it is bordered by an outwash terrace. On the ridge 3 to 4 miles northwest of Brooklyn drift of the Brooklyn moraine mantles the crest outside the later moraine; and 1 to 2 miles southeast of the Illinois Central the Brooklyn moraine merges with or disappears beneath the Johnstown moraine. On the ridge just southeast of the Illinois Central Railroad the surface of the rock is barely covered by loamy clay soil and scattered erratics of the older Illinoian drift sheet. At the angle north of Brooklyn a narrow, sharp, marginal ridge rises abruptly 60 feet from the bordering flat. Thence northwestward the margin is generally less abrupt but is clearly marked; and near the border its surface is very uneven from the many sags and swells and sharper undulations. Back from the outer margin the sags and swells are very slight and the inner margin, except where bordered on the northeast by later outwash plains or marshes, is very indefinite. The greatest thickness known of drift in the moraine in Oregon Township, in the valley north of Brooklyn, is 150 feet, and the estimated average is 62 feet.

The estimated average thickness of drift in the whole moraine thus far described, from Richmond to the southeast part of Verona Township, Dane County, a distance of about 45 miles with an areal extent of about 117 square miles, is 119 feet. As this is an excess of 74 feet over the estimated average thickness of drift outside this moraine, it may perhaps give some indication as to the thickness of earlier drift overridden by the Green Bay Glacier and included in the above computed thickness.

Beyond the Illinois Central Railroad the moraine becomes very abrupt in sec. 36, T. 6 N., R. 8 E. (Verona Township), where there is a sharp narrow ridge 100 feet in height strewn with abundant crystalline bowlders. Back of this margin are slight sags and swells. Thence northwestward to Verona the moraine front is well marked but less abrupt, overlying dissected St. Peter sandstone and Lower Magnesian limestone. Crossing an ancient valley at Verona, where it is cut through by Badger Creek, the moraine continues northwest up a second old tributary to Sugar River. For 1½ miles north of the line of the Chicago, Milwaukee & St. Paul Railway the glacier occupied the valley and left its moraine crowded against the west slope, being separated therefrom by only a sharp narrow ravine 35 to 40 feet in depth. One side of this ravine, which was probably kept open by the southward flow of the glacial waters, is of nearly bare Lower Magnesian limestone; the other is formed by the abrupt front of the moraine. Through the next 1½ miles the moraine front rises abruptly 60 to 80 feet from a flat terrace to a well-marked ridge crest, back of which a belt one-half to 2 miles in width, marked by gentle sags and swells and several ponds, extends to a very indefinite inner margin. Near the north line of Verona Township the moraine crosses the old valley and ascends 120 feet to the crest of the Trenton-capped ridge beyond. Wells indicate thicknesses of 18 to 80 feet for the moraine in Verona Township, the average of 16 measurements being 46 feet. In sec. 5 the moraine is cut through by a narrow ravine 80 to 100 feet in depth, whose lower slopes and bottom expose the St. Peter sandstone and Lower Magnesian limestone.

Outside the moraine near the town line the limestone crest of the ridge is covered only by thin clay soil and scattered bowlders which probably came from the moraine or the ice front itself. Here for the first time, tracing it from the southeast, does the moraine reach the Driftless Area and mark the limit of glaciation for this part of the State. For 85 or 90 miles northward from this point no earlier glacier is known to have extended farther west in Wisconsin than the Green Bay Glacier of the later Wisconsin substage; and from this moraine front westward to the Mississippi, a distance of 75 to 80 miles, no unmodified glacial drift has ever been found. The relations of the Green Bay Glacier and its deposits to this thoroughly dissected erosion topography are instructive. For 2 miles in southwestern Middleton Township the ice front lay along the east slope and crest of the rock ridge and deposited its moraine there and in the heads of the ravines which cut the western slope. It is remarkable that no outwash deposits lead down these ravines away from the moraine. Possibly most of the water drained backward down the east slope of the ridge beneath the ice. In sec. 30 the rock ridge swings westward about a mile across the line into Cross Plains Township. The ice did not press forward to the head of the valley thus extended but deposited its moraine across the valley in such a manner as to leave the upper part an inclosed basin 60 to 80 feet in depth. The west front of the morainal dam is bordered by a narrow flat terrace deposited in a temporary lake which occupied the basin. From this terrace the slope rises abruptly 30 to 40 feet to a narrow crest marked by parallel ridges and sharp kettles and many bowlders from which a long gentle slope drops down eastward to an indefinite inner margin. Mr. Voss's well near the top of this slope, at a point about 30 feet lower than the crest, reached rock at a depth of 130 feet.

North of this valley is a high limestone divide between the Sugar River basin and the Black Earth Valley. The rock ridge, before it was covered by the drift, had a relief of 140 to 200 feet on the south and of 300 feet or more on the north. In overriding this ridge obliquely a notch or reentrant three-fourths mile in depth was developed in the glacial margin. This indicates that the extreme frontal slope of the ice rose about 200 feet in the first mile from the edge. The moraine ascends the south slope, its crest reaching, in the SE. ¼ sec. 18, T. 7 N., R. 8 E., the highest elevation thus far attained, 1,239 feet above sea level. Just how much drift there is at this point is not known, but rock is exposed in the slope and reached in wells 80 to 100 feet lower beneath 20 feet of drift within half a mile. An average of the thicknesses of drift penetrated in the moraine in Middleton Township by 10 wells is about 60 feet. Continuing northwestward the front of the moraine runs for a mile along the crest of the south bluff of the Black Earth Valley as a small marginal ridge 150 to 200 feet above the bottom of the partly filled valley to the north, where it blocks the heads of two ravines. In the NW. ¼ sec. 13, T. 7 N., R. 7 E. (Cross Plains Township), it drops down the slope into the valley where, in crossing obliquely, its relief is lost in the general filling of moraine and outwash deposits.

In the NE. ¼ sec. 11 a narrow marginal ridge 15 to 20 feet high extends up the north slope of the valley and thence across the heads of ravines and intervening ridges one-fourth mile or less back of the crests of the bluffs, which rise abruptly 100 to 140 feet from the flat floor of the partly filled valley. The surface of this drift is thickly strewn with erratic bowlders, but outside its margin not a piece of drift is found in the thin clay soil. Within the marginal ridge, drift marked by slight sags and swells mantles the rock ridge, but the moraine is not bulky and its inner limit is poorly defined.

The converging of valleys from the east and northeast at Cross Plains led to the ice front crowding forward slightly into the narrow opening between the heads of opposite salients. Here the moraine is pitted with slight sags through a width of a mile and has a relief of 20 to 40 feet above the flat outwash plain to the west. The contrast between the craggy bluffs capped with Lower Magnesian limestone outside the moraine and the smoothly rounded slopes within it is very striking in the vicinity of Cross Plains.

Northwestward from Cross Plains to the Wisconsin River valley, a distance of about 10 miles, the limit of glaciation is generally plainly marked by a narrow marginal ridge with plentiful bowlders. This ridge is a few rods in width and rarely more than 20 feet high, but it is traceable continuously across a greatly dissected topography of five rock ridges 200 to 250 feet in height and four intervening valleys. After leaving the valley at Cross Plains, the surface shows, for the most part, only the smooth undulating contours of ground-moraine topography. It looks as though the bulk of the morainal deposit was not formed at the limit of the advance in this part but is represented by the morainal belt which leaves the marginal ridge just north of Cross Plains and thence northward lies about 2 miles farther east.

For a mile north of Cross Plains the ice pressed against the east slope of the rock ridge fitting snugly into the ravines, as shown by the little marginal ridge which encircles their heads. The crossing of this first ridge causes a reentrant of nearly three-fourths mile, the ice having pushed forward in the next valley. Two to three miles farther northwest a reentrant of one-half mile resulted from overriding a ridge 250 feet high, the ice pressing forward in the valley west of Marxville. So also on the broad low tract near Wisconsin River the ice extended about a mile farther west than on the narrow crest on the south, which rose 300 to 400 feet higher.

The deposit which separates from the marginal ridge north of Cross Plains merges with it again in the broad valley west of Roxbury. The limits of this morainal belt are very indefinite, its presence usually being indicated only by sags and kettles which pit the surface. A mile west of Martinville, however, in adjacent parts of secs. 11, 12, 13, and 14, T. 8 N., R. 7 E. (Berry Township), some of the most strongly marked morainal topography within the region occurs. One bulky ridge which appears to be of drift has a relief of 160 feet on the west; and its crest stands 1,249 feet above sea level, or about 400 feet above the rock bottom of the partly filled valley at Marxville, 3 miles to the northwest. The average thickness of drift penetrated by 16 wells in this morainal belt in the towns of Cross Plains and Berry is about 55 feet. These depths range from 25 to 95 feet, several of them not reaching the base of the drift.

Columbia County.—In the northwestern part of Roxbury Township and in Westpoint Township the Lower Magnesian limestone is so far removed that the upland breaks up into separated hills and ridges, which, before the deposition of the drift, rose abruptly 100 to 400 feet or more from rather broad lower areas excavated in the Cambrian sandstone; beyond this, in Prairie du Sac, Sumpter, and Merrimac, the valley of Wisconsin River also cut the sandstone. In this hilly part the terminal moraine has a somewhat different form. A broad pitted filling of considerable thickness is spread out in the valleys, but the ridges are but thinly covered and rarely show morainal topography. The relation of the extreme margin to some of the bluffs is interesting. The bluff directly opposite Prairie du Sac (Pl. VI, p. 33) rises about 380 feet above the river. Before the Wisconsin Valley was filled with drift this relief must have been at least 200 feet greater. The ice surmounted the rock ridge and pushed westward nearly to the crest of the west-facing bluff, but it did not glaciate either the bluff face or about 20 acres of the flat top above it, though it closed in somewhat about the lower slopes and filled the front with outwash gravels. The margin is traceable as a slight ridge up the south spur of the bluff, looping back in all about three-fourths mile across the flat top and dropping down again along the crest of the narrow north spur. About a mile north of this the narrow ridge called Black Hawk Bluff rises to a similar height. About 30 rods of the extreme point of the bluff must have protruded from the front slope of the ice, for no drift is found upon this part, though the moraine buries the lower slopes. An excellent view of the mildly pitted morainal topography to the north is to be had from this crest. (See Pl. XXII, *B*, p. 205.) South of the river the separation of the outer moraine from the moraine lying next to the east is rather indefinite except where rock ridges intervene. The thickness of the drift filling between these several ridges ranges from 20 to 140 feet, the average penetrated in 16 wells being 82 feet. Much of the outwash bordering the moraine south and east of the river has been cut away by the stream in developing an alluvial terrace and excavating its present channel.

Sauk County.—Between the river and the quartzite ranges the moraine is bordered on the west by a broad, flat, outwash plain. From this a well-marked frontal slope rises 20 to 60 feet to the crest of a marginal ridge which is generally less than a mile in width. The surface of this ridge is not strongly pitted but is marked by gentle sags and swells. East of this, through an additional width of 2 miles, are slight sags, gentle undulations, and some nearly flat tracts. The shallow valley east of the railway is regarded as separating the outer moraine from that next east. So far as known to the writer none of the wells between the river and the quartzite range reach the rock bottom of the ancient Wisconsin Valley, though a dozen or more are reported as having penetrated drift to depths varying from 50 to 220 feet.

The relations of the terminal moraine to the south quartzite range are particularly interesting. These have been previously described by R. D. Salisbury and W. W. Atwood, who say:[1]

For the sake of bringing out some of its especially significant features the ridge may be traced in detail, commencing on the south side of the west range. Where the moraine leaves the lowlands south of the Devils Nose and begins the ascent of the prominence the marginal ridge first appears at about the 940-foot contour. Though at first its development is not strong, few rods have been passed before its crest is 15 to 20 feet above the Driftless Area immediately to the north and from 40 to 100 feet above its base to the south, down the slope. In general the ridge becomes more distinct with increasing elevation, and except for two or three narrow postglacial erosion breaks is continuous to the very summit at the end of the nose. The ridge, in fact, constitutes the uppermost 40 or 45 feet of the crest of the nose. Throughout the whole of this course the marginal ridge lies on the south slope of the nose and has the asymmetrical cross section shown. Above (north of) the ridge at most points not a bowlder of drift occurs. So sharply is its outer (north) margin defined that at many points it is possible to locate it within the space of less than a yard.

At the crest of the nose the marginal ridge, without a break, swings northward and in less than a quarter of a mile turns again to the west. Bearing to the north, it presently reaches the edge of the precipitous bluff bordering the great valley at the south end of the lake. Between the two arms of the loop thus formed the surface of the nose is so nearly level that it could have offered no notable opposition to the progress of the ice, and yet it failed to be covered by it.

In the great valley between the nose and the east bluff the marginal ridge does not appear. In the bottom of the valley the moraine takes on its normal form, and the slopes of the quartzite ridges on either hand are much too steep to allow any body of drift or loose material of any sort to lodge on them.

Ascending the east bluff a little west of the point where the drift ridge drops off the west bluff, the ridge is again found in characteristic development. For some distance it is located at the edge of the precipitous south face of the bluff. Farther on it bears to the north and soon crosses a col in the ridge, building it up many feet above the level of the bedrock. From this point eastward for about 2 miles the marginal ridge is clearly defined, the slopes about equal on either side, and the crest as nearly even as the topography of the underlying surface permits.

At [Point Sauk] this marginal ridge attains its maximum elevation—1,620 feet. At this great elevation the ridge turns sharply to the northwest at an angle of more than 90°. Following this direction for little more than half a mile, it turns to the west. At some points in this vicinity the ridge assumes the normal morainic habit, but this is true for short distances only. Farther west * * * it turns abruptly to the northeast and is sharply defined. It here loops about a narrow area less than 60 rods wide and over half a mile in length, the sharpest loop in its whole course. The driftless tract inclosed by the arms of the loop is lower than the drift ridge on either hand. The ice on either hand would need to have advanced no more than 30 rods to have covered the whole of it.

From the minor loop just mentioned the marginal ridge is continued westward, being well developed for about 1½ miles. At this point the moraine swings south to the north end of Devils Lake, loses the unique marginal ridge which has characterized its outer edge across the quartzite range for so many miles, and assumes the topography normal to the terminal moraines. At no other point in the United States, so far as known to the writers, is there

[1] Salisbury, R. D., and Atwood, W. W., The geography of the region about Devils Lake and the Dalles of the Wisconsin: Wisconsin Geol. and Nat. Hist. Survey Bull. 5, pp. 93, 94, 105–111, 1900.

so sharply marked a marginal ridge associated with the terminal moraine for so long a distance.

From the map [Pl. III, in pocket] it will be seen that the moraine as a whole makes a great loop to the eastward in crossing the quartzite range. From the detailed description just given of the course of the marginal ridge it will be seen that it has three distinct loops; one on the Devils Nose, one on the main ridge, and a minor one on the north side of the last. The first and third are but minor irregularities on the sides of the great loop, the head of which is at * * * [Point Sauk].

The significant fact in connection with these irregularities in the margin of the moraine is that each loop stands in a definite relation to a prominence. The meaning of this relation is at once patent. The great quartzite range was a barrier to the advance of the ice. Acting as a wedge it caused a reentrant in the advancing margin of the glacier. The extent and position of the reentrant is shown by the course of the moraine. Thus the great loop in the moraine was caused by the quartzite range itself.

The minor loops on the sides of the major are to be explained on the same principle. Northeast of the minor loop on the north side of the larger one there are two considerable hills reaching an elevation of nearly 1,500 feet. Though the ice advancing from the east-northeast overrode them, they must have acted like a wedge to divide it into lobes. The ice which reached their summits had spent its energy in so doing, and was unable to move forward down the slope ahead, and the thicker bodies of ice which passed on either side of them failed to unite in their lee. The application of the same principle to the loop on the Devils Nose is evident.

The material in the marginal ridge, as seen where erosion has exposed it, is till, abnormal, if at all, only in the large percentage of widely transported bowlders which it contains. This is especially true of the surface, where in some places 90 per cent of the large bowlders are of very distant origin, and that in spite of the fact that the ice which deposited them had just risen up over a steep slope of quartzite, which could easily have yielded abundant bowlders. In other places the proportion of foreign bowlders is small—no more than 1 in 10. In general, however, bowlders of distant origin predominate over those derived close at hand.

The marginal ridge on the south slope of Devils Nose leads to an inference of especial interest. Its course lies along the south slope of the nose from its summit on the east to its base on the west. Throughout this course the ridge marks with exactness the position of the edge of the ice at the time of its maximum advance, and its crest must therefore represent the slope of the upper surface of the ice at its margin.

The western end of the ridge has an altitude of 940 feet and its eastern end is just above the 1,500-foot contour. The distance from the one point to the other is 1¾ miles, and the difference in elevation 560 feet. These figures show that the slope of the ice along the south face of this bluff was about 320 feet per mile. This, so far as known, is the first determination of the slope of the edge of the continental ice sheet at its extreme margin. It is to be especially noted that these figures are for the extreme edge of the ice only. The angle of slope back from the edge was doubtless much less.

The marginal ridge described above is very similar in character and topographic relations to the narrow ridge marking the limit of glaciation for about 10 miles between Cross Plains and Wisconsin River. (See p. 213.) In the gorge east of Kirkland the morainal dam has a relief on the east of 200 feet. On the west it is bordered by a flat terrace sloping westward to the lake. There is at least 450 to 500 feet of drift in the gorge at this place. The narrow marginal ridge does not constitute all of the terminal moraine on the quartzite ridge, as might be inferred from the above description. On the glaciated side of the marginal ridge, morainal drift pitted with slight sags and some sharper kettles and set with knolls is spread over the crest and slopes of the quartzite ridge, where they are not too steep, through a belt a mile or more in width. For 4 miles the whole north slope of the south range is thus mantled. In places wells show considerable thicknesses of drift, indicating that the slopes of the quartzite ridge were cut by one or more valleys which are now filled with drift. Three wells, two of them on the small lacustrine plain shut in by the moraine on the top of the south range, are reported to have penetrated thicknesses of 130, 151, and 201 feet of drift.

In the Baraboo Valley between the ranges the ice advanced to a position 6 miles farther west than Point Sauk. The difference in altitude between Point Sauk and the rock bottom of the Baraboo Valley is about 1,050 feet. The relief on the south was probably even greater. After blocking the Devils Lake Gorge at the north end of the lake, where there is probably 400 feet of drift, the moraine continued west and north across the Baraboo Valley, marking the front of the ice lobe in the valley. The probabilities of much of this filling being of earlier age have already been discussed. There is here a marginal ridge one-half to three-fourths mile in width, bordered on the west by an outwash terrace which in places rises to the moraine crest, and elsewhere the front slope of the moraine rises 20 to 40 feet above the terrace. The surface of the ridge is but little marked by sags, and the gentle slope declining eastward from the crest shows only the contours of the ground moraine. The writer is, however, inclined to include with the marginal ridge the tract extending 2 to 2½ miles farther east as constituting the terminal moraine in the valley. This is done because of the character and relations of the deposit, including some north-south ridging, in this belt, and because such a width corresponds with the breadth of the moraine both to north and south. The inner or east margin of the moraine is indefinite and must be drawn more or less arbitrarily. The deposit is now cut through by the new valley of Baraboo River, which at the moraine front is about 120 feet in depth, exposing quartzite beneath the drift. Correlation of the records of wells and of test borings for iron ore show that the ice pushed westward along the deep valley to a point where it narrowed and tributaries converged. Here the marginal deposit was left overlying slopes, rock points, and the intervening valleys. That the amount of filling between the north and south quartzite ranges is considerable is indicated by the fact that of 43 wells and test holes concerning which information was obtained 15 reached the underlying rock at 18 to 240 feet, and 28 did not reach rock at 60 to 267 feet. The average thickness shown by these is about 138 feet. The question whether all of this is drift of the last ice invasion is further considered subsequently. (See p. 225.)

On the north quartzite range the moraine has a width of 2 to 3 miles, as shown by a gentle sag and swell topography. This width it maintains due northward for 8 miles from the quartzite range to Wisconsin River, overlying a broad valley in the Cambrian sandstone. The marginal ridge is well marked through most of this distance, its west slope rising 30 to 70 feet above a flat sandy plain on the west. About 3 miles northwest of Baraboo, near the southeast corner of Delton Township (T. 12 N., R. 6 E.), for about a mile the crest of the ridge flattens and a closely pitted plain marks the position of the ice front. From the crest of this ridge the surface drops eastward with gentle undulations and here again there is difficulty in deciding what should be regarded as the inner border of the terminal moraine. Lying between the north range and the river with the main morainal ridge on the west and the big marsh on the east, is an area of rather low sandy hills of smooth contour, with some north-south ridging and, in places, slight sags. The writer is inclined to think that a part, at least, of this should be included with the terminal moraine. The topography is somewhat different from any farther south and the last of the drift was probably deposited in waters ponded in front of the retreating ice front and might be considered glacio-lacustrine. Fourteen wells between the north range and the river, in the main morainal belt, penetrated thicknesses of drift ranging from 30 to 292 feet, most of them not reaching the underlying rock. This indicates an average thickness of at least 136 feet of drift. The well of G. L. Fish (see log, p. 219), in the NW. ¼ sec. 23, T. 13 N., R. 6 E., Delton Township, which penetrated 292 feet of drift to rock, is within one-half mile of the most easterly of the sandstone outcrops on the river to the north. The termination of the rock gorge at this point indicates that here the river leaves its postglacial channel and flows out upon the drift which fills its earlier wide valley in the sandstone. The well curb is about 130 feet above the river, so that the rock at its bottom is 160 feet below the level of the present stream. The ice (see Pls. II and IV, in pocket) advanced westward to the west side of the broad preglacial valley and there deposited its terminal moraine along the upper west slope. At least 17 feet of the material penetrated by Fish's well was probably deposited before the last glaciation.

Adams County.—North of the river the moraine shifts about 1½ miles farther east in consequence of the projection of an underlying sandstone ridge and then continues its northerly trend through the towns of Dell Prairie and New Haven, with dimensions and configuration about the same as south of the stream. In this part the bordering outwash plain is very well developed, sloping gently to the west. From it the regular wooded front slope of the moraine rises 20 to 50 feet to the crest of a well-defined marginal ridge. East of this the surface shows slight sags in part and elsewhere gentle undulations characteristic of ground moraine. Crystalline bowlders are plentiful on the surface but are not usually very abundant. Where not defined by marshy flats the eastern limit of the moraine is indefinite and must be drawn rather arbitrarily. The average width is about 2 miles. Thirty-eight wells, half of which did not reach the underlying rock, penetrated drift to depths of 20 to 200 feet, the average being about 55 feet.

In Jackson and Oxford townships (T. 15 N., Rs. 7 and 8 E.) two morainal ridges, which are distinctly separated from the outer moraine farther south, merge with the Johnstown moraine in a morainal belt 5 to 6 miles in width. This is not sharply knolled and pitted but is marked by broad swells and sags and some large kettle depressions. The soil is loose and sandy; and cuts expose sand, sand and gravel, or sandy till. The larger part of this belt is not under cultivation but is covered by a scanty growth of jack oak, white oak, and brush. Of the few bowlders some are from the granite exposed at Montello and are of large size. So far as reported to the writer, none of the wells in this tract reach the sandstone though penetrating 50 to 194 feet of drift, principally sand and gravel. Reddish clay is exposed at a few places and is said to have been penetrated in a few wells beneath considerable sand and gravel. In one of these, that of Ole Sorenson, in the NW. ¼ sec. 12, Jackson Township, 40 feet of stoneless reddish clay was penetrated beneath 20 feet of sand. Gravel lay below the clay. There seems to be no evidence, however, that a continuous bed of such clay lies beneath the outer, or Johnstown, morainal deposits.

Through New Chester Township, the western 1¾ to 3 miles of the morainal belt, which corresponds to the Johnstown moraine farther south, is higher and more ridgelike than that to the east. The surface is marked by big swells and depressions, not by sharp kames and kettles. This part has a more or less definite east margin. The west front slope rises rather abruptly 50 to 100 feet above the extensive flat sandy plain on the west. The crest of the moraine ranges from 1,000 to 1,100 feet above sea level. The soil on the moraine is sandy and the surface carries considerable second-growth timber. But few well data were collected in this township. Wells in the north part of the township are said to penetrate drift to depths of 100 to 150 feet farther south. Two wells were reported to have been drilled to depths of 100 to 110 feet without reaching rock.

Northeastward, in sec. 12, T. 17 N., R. 7 E. (Lincoln Township), an outer morainal belt about three-fourths mile in width is separated from the morainal topography to the east by a nearly flat terrace or plain of about the same width. This terrace looks, in part at least, as though it had been formed by an outwash of sand and gravel when the ice front had retired to the morainal belt on the east. For about 5 miles, therefore, the outer moraine, which probably represents the Johnstown moraine, is distinct from the later deposits. In the northwestern part of Springfield Township the belts again merge.

Through Lincoln Township the west front of the moraine trends about N. 35° E. Northeastward from a bold wooded ridge at the south the crest lowers in places and the flat sandy plain on the west rises gradually. In sec. 27 and for about 1½ miles in secs. 11, 14, and 15, the immediate front of the moraine becomes the lower, forming an elongated sag or fosse, into which short abrupt back slopes drop from the plain bordering on the west. In sec. 11 the glacier advanced just to the foot of the south slope of the big sandstone bluff and there made its marginal deposit. Northeastward in the NW. ¼ sec. 12 the relief of the moraine increases, and in the SE. ¼ the drift margin loops back across the crest of a bold sandstone ridge. Thence north-northeastward into and through Waushara County the west front of the moraine rises above the flat bordering plain as a bold line of wooded bluff about 100 feet in height.

THICKNESS OF THE DRIFT OF THE MORAINE.

The average thickness of drift in the moraine between Richmond and southeastern Verona townships, a distance of 45 miles, is estimated from the records of 210 wells and some other data to be about 119 feet. Omitting the filling of the Wisconsin Valley south of the quartzite ranges, where none of the wells penetrate the full thickness of the drift and omitting also the drift on the south quartzite range, where the thickness shown by the few wells noted is greatly in excess of the probable average, the records of 160 wells give an average thickness of 89 feet for the 66 miles from southeastern Verona Township to New Chester Township. Combining the two we have, for the whole 111 miles from the 370 records, an estimated average thickness of about 106 feet.

If the thickness of the drift in the terminal moraine at the south end of the glacier is really as much greater than that in the moraine on the west side of the glacier as it appears to be from the differences in the estimated thicknesses (119 and 89 feet, respectively), it is a matter of some significance. One explanation, and perhaps the real one, may be found in the fact that from Verona Township northward the Green Bay Glacier extended beyond the limits of any earlier drift, and that southeast of Verona the last glacier fell far short of reaching the limit of the earlier drift sheet; hence the thickness estimated for the morainal belt in this south part may include one earlier drift sheet and perhaps part of another. If from the thickness of 119 feet estimated for the moraine at the south end of the Green Bay Glacier be deducted the 45 feet of estimated thickness of the pre-Wisconsin drift outside the terminal moraine and in the Brooklyn moraine (see pp. 151 and 185), there remains 74 feet, which may be regarded as representing deposition during the Wisconsin stage and which is somewhat nearer the 89 feet estimated as the thickness of the moraine on the west side of the glacier.

STRUCTURE AND COMPOSITION.

The surficial parts of this moraine, as shown by natural and artificial sections and wells, consist, in about three-fourths of the places noted, of till, largely rather sandy; but the bulk of the deposit is of sand and gravel with, in places, intercalated layers of clay. The following logs of a few of the deeper representative wells show the structure of the deposits:

Log of well in sec. 18, T. 3 N., R. 15 E. (Richmond Township).[1]

	Feet.
Soil	1
Quicksand and gravel	10
Blue clay	40
Gravel	179
Black soil	2
Galena dolomite	18
	250

The black soil in this section may perhaps be a remnant of a preglacial soil, for it immediately overlies the rock. The well at Harmony Creamery, 3 miles south of Milton Junction, was reported as being 307 feet deep, nearly all in sand. R. W. Cunningham's well in the NE. ¼ sec. 1, T. 3 N., R. 12 E. (Janesville Township), penetrated 236 feet of sand and gravel. These last two wells are located over the ancient valley of Rock River. The writer has no data in hand which show definitely how much of the filling of this valley is earlier glacial or earlier alluvium. (See p. 238.) The same is true of the filling of the ancient Yaharah Valley now occupied by Rock River below Fulton Center.

Log of Douglas Hopkin's well in sec. 20, T. 4 N., R. 12 E. (Fulton Township).[1]

	Feet.
Clay and gravel	100
Clay	100
Gravel	40
	240

Log of Bernard Riley's well in the SW. ¼ sec. 21, T. 4 N., R. 11 E. (Porter Township).[1]

	Feet.
Hardpan	60±
Sand	60±
Blue clay with streaks of gravel	80±
St. Peter sandstone.	

It is quite possible that at least the blue clay penetrated by this last well is part of an earlier filling of a tributary of the ancient valley that headed in the town of Oregon. Another well in the filling of this valley, in the NE. ¼ sec. 14, T. 4 N., R. 10 E. (Union Township), encountered cemented layers of gravel beneath 120 feet of sand. The following log is from a well in the upper part of the same valley:

Log of Reuben Hebner's well in sec. 25, T. 5 N., R. 9 E. (Oregon Township).[1]

	Feet.
Till	?
Gravel	?
Quicksand	?
Solid blue clay	40
Gravel	?
Trenton limestone	5
	155

The following shows the composition where the moraine blocks the head of the valley 5 miles northwest of Verona:

Log of Mr. Voss's well in the NW. ¼ sec. 30, T. 7 N., R. 8 E. (Middleton Township).[1]

	Feet.
Clay	75
Sand and gravel	55
St. Peter sandstone	35
	165

The following log is representative of several wells in the part of the moraine which lies across the Wisconsin River valley south of the Baraboo quartzite ranges. The possibility that the sand and gravel below the till is in reality an earlier or pre-Wisconsin alluvial filling has been discussed. (See pp. 191–193.)

[1] Data from owner.

Log of R. Roick's well in the NE. ¼ sec. 14, T. 10 N., R. 6 E. (Sumpter Township).[1]

	Feet.
Sand	8
Till	60
"Shot gravel"	4
Sand	53
	125

The logs of three wells on the moraine in the Baraboo Valley between the north and south quartzite ranges follow. There is good reason for thinking that a part of this material is an earlier deposit.

Log of J. W. Steuber's well in the NW. ¼ sec. 3, T. 11 N., R. 6 E. (Baraboo Township).[1]

	Feet.
Blue clay Sand	100±
Sand Stony clay	120±
	220±

Log of Louis Marquardt's well in the NE. ¼ sec. 14, T. 11 N., R. 6 E. (Baraboo Township).[1]

	Feet.
Sand (mostly)	175
Clay	11
	186

Log of Daniel Ruggles's well, corner of Ninth Avenue and Park Street, Baraboo, Wis.[2]

	Feet.
Drift, mostly sand and gravel	276

The following is the log of G. L. Fish's well, which penetrates the moraine within one-half mile of the point where Wisconsin River leaves its postglacial channel below the Lower Dells and flows on the filling of the ancient valley. The well reaches rock at 160 feet below the present level of the river, so that at least a part of the lower 160 feet may be alluvium or earlier drift. Very likely the lower 30 feet or so, including the vegetal remains, is alluvium.

Log of G. L. Fish's well in the NW. ¼ sec. 23, T. 13 N., R. 6 E. (Delton Township).[3]

	Feet.
Drift, mostly sand and gravel with streaks of clay, one at 175 feet and a thicker one at 275 feet. Pieces of twigs and branches of wood through the lower 12 to 15 feet	275
Quicksand and gravel	17
Cambrian sandstone	20
	312

[1] Data from owner.
[2] Data from E. W. Van Akin, driller.
[3] Data from N. Wheeler, driller, Reedsburg.

Several railway and stream cuts give opportunity for observation of the morainal structure. Rock River has cut a narrow outlet through the moraine in the towns of Fulton and Janesville. The slopes are generally so well grassed over that the drift is not exposed. At one point the east slope showed gravel and unassorted drift over sand.

In sec. 1, T. 5 N., R. 8 E. (Montrose Township), 2 miles southwest of Fitchburg, the Illinois Central Railroad cut, nearly one-half mile long and 40 feet in maximum depth, exposes beneath the gentle outer slope of the moraine 5 to 6 feet of clay overlying 1 to 15 feet of coarse subangular gravel. About halfway to the viaduct light-buff, rather sandy calcareous till, leached to a depth of 5 to 7 feet, overlies coarse limestone gravel containing a great abundance of basic crystalline bowlders 1 to 3 feet in diameter. Within 10 rods of the viaduct and thence northeastward the drift exposed is mostly buff till over coarse morainal gravel. A great number of basic crystalline bowlders including a few of purplish quartzite were thrown out in making the cut.

One to four miles north of Prairie du Sac ravines eroded in the high banks, where the Wisconsin cuts through the moraine, afford exposures. (See Pl. XIX, *B*, p. 171.) A generalized section of several of these follows:

Section of Johnstown moraine on Wisconsin River northeast of Prairie du Sac.

	Feet.
Brown loamy soil and bowlders	0–2
Sandy bowldery till, partly stratified	25–50
Stratified sand, cross bedding dipping largely southeast	35–60

At one place near the west front of the moraine there is, beneath 6 feet of till, interstratified sand and fine gravel with layers of highly calcareous brown to bluish clay. The base is nearly horizontal and is sharply marked by a 3-inch layer of hard blue clay, beneath which is 65 feet of sand, mostly stratified horizontally but with some cross beds dipping principally east and southeast. The sand is clean and fresh and looks no older than the rest of the deposit. It may be an earlier filling of the ancient Wisconsin Valley or it may be sand washed out by glacial waters in front of the advancing ice, the overlying till being the deposit of the ice when it reached its maximum extension. At the exposure last noted the top of the interstratified sand and clay is poorly defined and the beds turn up into the till as though disturbed by the push of the ice. At these exposures reddish and purple quartzites, probably derived from the east end of the Baraboo Bluffs to the north, are numerous. The relation of the sand underlying the till and the possibility of its being a pre-Wisconsin alluvial deposits is considered in another connection. (See pp. 191–193.)

Figure 14 is a section of the Johnstown moraine made when the cut of the Chicago & Northwestern Railway in the Devils Lake Gorge east of Kirkland was fresh and clean.[1]

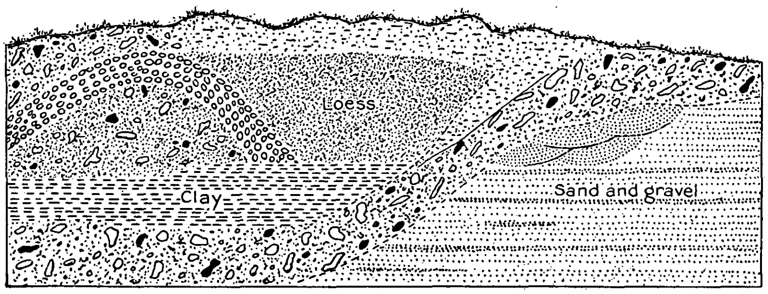


FIGURE 14.—Section of Johnstown moraine east of Kirkland, Wis., partly diagrammatic. (After Salisbury and Atwood.)

The stratified sand to the right retains even the ripple marks which were developed when it was deposited. To the left, at the same level, there is a body of till (unstratified drift), over which is a bed of stoneless and apparently structureless clay. In a depression just above the clay, with till both to the right and left, is a body of loam which possesses the characteristics of normal loess. It also contains calcareous concretions, though no shells have been found.

The stratified drift in the section was probably deposited in the extended lake which occupied the gorge while the ice fronts stood at this moraine at the east and at the ridge at the north end of the gorge.

Two miles southeast of Kilbourn, where the moraine is cut through by Wisconsin River, the cut for the Chicago, Milwaukee & St. Paul Railway at the north side of the stream gives a 60-foot section of drift which, when visited by the writer, was somewhat obscured by slumping and wash. The drift here appears to consist of beds of sand intercalated with sandy bowldery drift. A thin coating of loess extends about halfway up the west slope but is not very clearly differentiated from the sandy drift below. The top of the cut lowers a few rods to the east, and here the coating of loess is better defined, being in places 5 to 6 feet thick. This also mantles the crest of the moraine north of the railway. One-half mile farther southeast is exposed 40 feet of loose sand and coarse gravel overlain by 10 feet of typical buff, brownish-banded stoneless non-calcareous loess, standing with vertical face and columnar cleavage. Some large bowlders lie on the surface of the sandy drift buried in loess; one is a 6-foot quartz porphyry, another a gabbro with solid core, surrounded by a 4-inch zone of disintegrated rock. The relations of the loess are considered further on pages 343 and 344. The stratified drift was doubtless deposited in the lake that bordered the ice front from Devils Lake northward as long as the outlet around the east end of the quartzite ranges was blocked by ice.

In August, 1910, a steam shovel, excavating the crest of the moraine in the SW. ¼ sec. 16, T. 16 N., R. 7 E. (New Chester Township), for the grade of the new line of the Chicago & North Western Railway, had exposed a 10 to 40 foot section of the upper part of the moraine. Some banded or stratified sand was exposed in the northwest end of the cut, and there was much of the same toward the southeast end, but the central part was pebbly sandy till. Other shallower cuts showed similar sandy drift.

LITHOLOGIC COMPOSITION.

In order to obtain somewhat definite information as to the derivation of the drift composing the Johnstown moraine about 8,000 pebbles were taken indiscriminately from the drift exposed at 60 points distributed along the moraine from Walworth County to Adams County. These were sorted and the percentages of the different rock constituents were noted. It was found that an average of 86.98 per cent of these pebbles were from the rock formations underlying the drift in various parts of the area under investigation. Only 13.2 per cent were regarded as of foreign derivation, and these were almost all pebbles of the crystalline rocks of Canada, principally granite, diorite, gneiss, various schists, some basalts, greenstones, quartz porphyries, and quartzites.

[1] Salisbury, R. D., and Atwood, W. W., Wisconsin Geol. and Nat. Hist. Survey Bull. 5, p. 106, 1900.

Nuggets of copper from the Lake Superior region and one diamond from an unknown Canadian source were among the least common constituents found along this moraine.[1] The diamond was found on Judson Devine's place, 2½ miles southwest of the village of Oregon. The crystalline pebbles generally ranged from 5 to 20 per cent, in most analyses being less than 15 per cent, and in 10 (of pebbles collected in the towns of Merrimac, Fairfield, Delton, Newport, and Dell Prairie) being 21 to 45 per cent. These high percentages were probably due in part to the introduction of pebbles from crystalline knobs that project through the lower Paleozoic rocks in Columbia, Green Lake, and Marquette counties which were not always distinguishable from crystalline rocks of more distant derivation. In some analyses, however, the high percentage of crystalline matter shown was due to the disappearance of a large part of the limestone pebbles from the sandy drift.

Magnesian limestone is generally the chief constituent shown by these analyses, and this is almost wholly from the local formations. Niagara dolomite is shown by the analyses of pebbles from the interlobate angle and the vicinity of Rock River, in the town of Janesville. Its percentage decreases westward from 55 to 2 per cent. In only a few places west of Janesville Township were pebbles found that were thought to have come from the Niagara dolomite, the chief constituent being the Galena dolomite, pebbles from which, in places, range as high as 81.5 per cent. Farther westward the Galena constituent decreases, giving place to the Trenton, which almost entirely replaces it from Milton Township to Middleton Township, forming 1 to 75 per cent of the whole.

Pebbles from the Lower Magnesian began to be noticed in T. 3 N., R. 11 E. (Center Township), west of Rock River and continued to be present all the way north along the west side of the area of the glacier. From Center to Middleton Township (T. 7 N., R. 8 E.) the Lower Magnesian percentage ranges from 6 to 35. From Middleton to Merrimac material from the upland underlain by this limestone ranged from 54 to 87 per cent. Thence northward across the Wisconsin Valley and the Baraboo quartzite bluffs the Lower Magnesian constituent varied greatly (1 to 61 per cent) from place to place. North of Delton there was less variation, 37 to 78 per cent generally being present. With this material is grouped that derived from the Mendota limestone which comes largely from the Madison region. All the limestone formations except the Mendota carry considerable chert in certain parts. Over the Galena belt there is generally 1 to 6 per cent, but in the Trenton belt it is scarcely shown by the analyses. With the incoming of the Lower Magnesian material, however, from Middleton northward, it increases, forming in one place, where the limestone itself nearly disappears, 25 per cent of the pebbles.

Owing to the friable character of the sandstones these formations yield sand rather than pebbles to the drift, wherefore (these estimates being based only on pebbles) the percentage of sandstone in the drift is probably underestimated especially along the southwestern and western sides of the lobe where the drift is more sandy from the contributions of these formations than farther east where limestones so greatly predominate. East of Rock River as many as 6 per cent of the pebbles are sandstone. West of this stream the percentage ranges from 2 to 39.

East of the town of Janesville quartzite pebbles are not numerous, nowhere exceeding 3 per cent, and are probably mostly foreign. Thence westward to T. 4 N., R. 10 E. (Union Township), the moraine lies at the distal margin of the quartzite bowlder fan distributed southward from the ledges outcropping in the region of Waterloo, in northwestern Jefferson and southwestern Dodge counties. In this part of the moraine quartzite content ranges up to 9 per cent and in places quartzite bowlders are very abundant on the surface of the moraine. Between Union and Merrimac townships there is generally less than 2 per cent of quartzite. On and near the Baraboo quartzite ranges from Merrimack Township to Delton Township the estimates showed 7 to 39.5 per cent quartzite, which is probably almost all derived from the local ledges. North of Delton Township the quartzite content almost disappears.

Consideration of the distribution and relative abundance of these several constituents of the drift of the terminal moraine of the Green Bay Glacier, in connection with the relations of the deployment of the ice currents over the outcropping belts of the several rock formations,

[1] Hobbs, W. H., The diamond field of the Great Lakes: Jour. Geology, vol. 7, pp. 375-388, 1899.

shows that the drift is predominantly of local origin, and that most of the pebbles may have been derived from parent ledges within a comparatively few miles of their place of deposition. The material has, however, clearly been moved some distance and with it there is commingled, wherever examined, an average of nearly 14 per cent of material derived from formations which are not known to occur in the path of this glacier within less than 100 to 300 miles of the places of final deposition. However, among the bowlders scattered so abundantly over the surface of the moraine, the foreign constituent is much more notably in evidence. Except within the main train from the Waterloo quartzite ledges and within the train from the crystalline ledges of Columbia, Marquette, and Green Lake counties, the bowlders scattered over the surface of the moraine are predominantly foreign crystalline rock derived from formations in Canada. It is estimated that fully 90 per cent and perhaps even more of the surface bowlders, outside of these parts of the moraine which received local quartzites or crystallines, have traveled hundreds of miles to reach their destination. The inversion of the ratio between the percentages of foreign material on the surface of the drift as compared with that shown by the estimate of the constituents in the body of the drift would seem to indicate that the foreigners, which were transported so far, were carried well up in the body of the glacier and were among the last of the drift materials to be deposited when the ice finally melted. Although thorough commingling of local and foreign material would result from continued bringing forward and dumping at the glacial front, yet at each particular spot the last material to be deposited would likely be that highest up in the ice, so that a preponderance of these long-distance travelers would be left upon the surface. This predominance of foreign material among the bowlders on the surface of the drift is not confined to the terminal moraines but has been noted throughout the drift area, so far as studied in Wisconsin, except within the limits of local bowlder trains.

GLACIAL LAKES BARABOO AND WISCONSIN.

FORMATION OF THE LAKES.

The occupancy of the Baraboo Valley and of the Wisconsin Valley in the Baraboo region as far west as the moraine by the Green Bay Glacier caused a blocking of the drainage and the formation of glacial lakes which extended far up these valleys and their tributaries. (See Pl. III, in pocket.) The vanished lake in the Baraboo basin has been named "Baraboo Lake" by Salisbury and Atwood,[1] and the one in the Wisconsin Valley may be designated glacial Lake Wisconsin. The depth and dimensions of the preglacial valleys, as far as could be determined from reports from the drilling of 125 wells and test holes bored for iron, is shown on Plate II (in pocket). The bottom of the ancient Baraboo Valley in its deepest part is somewhat less than 600 feet above the sea. The valley floor is now a broad flat plain lying 870 to 900 feet above sea level, in which the river has cut its present channel, so that there is here a probable maximum thickness of nearly 300 feet of filling. The greatest thickness known to the writer to have been penetrated by the drill is 250 feet, a depth which was approximated at several places.

The water supply being in excess of the leakage and evaporation in these basins, as it undoubtedly must have been in Baraboo Lake, the maximum height to which the surface of Baraboo Lake rose would be determined by the elevation of the lowest point in the rim of the basin, or, if an outlet led into the neighboring basin which was itself submerged, the two lakes would be confluent and their height would be determined by the lowest point in the rim of the combined basins. Examination of the topographic maps shows two places where the divide between the Baraboo Valley and the Wisconsin Valley on the north has an elevation of 960 to 980 feet. These are in the NW. ¼ sec. 9, T. 12 N., R. 5 N. (Excelsior Township), and near the north line of Baraboo Township (Tps. 11 and 12, R. 6 N.), between the moraine and the rock ridge on the west.

West of the moraine and north of the quartzite ranges the lowest known col in the rim of the Wisconsin Valley is about 1,000 feet above sea level, near Mather, Jackson County, Wis., and it is probable that the waters of the two lakes were confluent and that they rose to the level of this lowest col.

[1] Salisbury, R. D., and Atwood, W. W., The geography of the region about Devils Lake and the Dalles of the Wisconsin: Geol. and Nat. Hist. Survey Bull. 5, p. 130, 1900.

OUTLET.

In July, 1910, the writer visited the outlet in company with G. A. Marvine, of Mather, Wis. The flat sandy plain with extensive marsh and swamp tracks extends over the greater part of the northern two-thirds of Juneau County. The elevations of this plain above sea level, according to railway surveys cited by Gannett,[1] are at Mauston 882 feet, at Camp Douglas 933 feet, at Valley Junction 929 feet, and at Mather 962 feet.

About 10 miles north and 4 miles west of Mather, in sec. 16, T. 21 N., R. 1 E., is the divide between Beaver Creek, a tributary to Wisconsin River via Lemonweir River, and Indian Creek, a tributary to Black River via Morrison Creek. The writer was informed that drainage surveys showed the divide to have an elevation of 41 feet above Mather station, or 1,003 feet above sea level. This agreed approximately with a barometric measurement made by the writer from Mather station as a base. A second col in sec. 36, T. 21 N., R. 1 W. (Knapp Township), between Beaver and Morrison creeks, is said to have a slightly lower elevation. The col visited by the writer at the former place is a nearly flat marsh 1 to 1½ miles wide, containing a considerable accumulation of vegetal material. There are no natural channels in this unless they are buried by the peat, which in places extends at least to the full depth of the drainage ditches (about 10 feet). The divide is imperceptible in the marsh, but to the west streams heading near the border of the marsh are said to soon cut down into sharp valleys. Marvine states that in the NE. ¼ sec. 21, T. 21 N., R. 1 E. (Bear Bluff Township), a bed of ashes was found 10 feet below the surface of the peat. He also states that at some points near Mather 3 or 4 peat beds with tree stumps and ashes have been found one above another. From this it appears that the present surface at the divide may perhaps be as much as 15 feet above what was the bottom of the col when it served as an outlet for the glacial lakes.

No evidence noted in the Baraboo basin indicates that Baraboo Lake rose above this level; indeed, all the indications of submergence fall a little short of this elevation. These phenomena are not such, however, as would show clearly the exact height of the water surface. No traceable shore lines are found. The evidence of the height of submergence consists in the occurrence on the valley slopes at a few points of gravels which may be beach gravels, and of crystalline pebbles and bowlders derived from the glacial drift, for whose presence there is no credible explanation except that they were dropped from floating ice, which might have become detached from the glacial front. (The supposed earlier greater extension of the ice in this region suggested by Weidman is considered on pp. 170–171.) There seems to be no way of disposing of the glacial waters and of other surface drainage into the Baraboo and Wisconsin valleys north of the quartzite barrier when the ice front occupied the moraine other than ponding in an extensive lake that discharged by the lowest col, supposing, of course, that the ice was not melted back from the moraine before such flooding could be accomplished. Of this there can hardly be question, considering the amount of drift concentrated in the terminal moraine. The accumulation of this mass of morainal drift means the advance and melting at this limit of a vast amount of ice, which, under conditions of glaciation, would require very many years.

The writer has not found these bowlders and gravel more than 960 to 980 feet above sea level on the slopes of the valley. On the ridge a mile south of the Excelsior creamery, sec. 24, T. 12 N., R. 5 E. (Excelsior Township), at an elevation of 960 feet a small pit exposes 3 feet of stratified discoidal pebbles of limestone and sandstone, mostly less than 2 inches in diameter, which closely resembles beach gravel and is thought to be such. No foreign crystalline pebbles were noted among these, though a few were seen scattered in the road near by. In a gully in the south slope in the NE. ¼ SE. ¼ sec. 6, T. 11 N., R. 5 E. (Freedom Township), about 2 miles southwest of Ablemans, numerous crystallines of several varieties were found with chert, quartzite, and sandstone pebbles up to a level about 60 feet above the flat, or 960 above sea level. Salisbury and Atwood[2] also cite an occurrence which was not seen by the writer, as follows:

At a point 3 miles southeast of Ableman on the surface of a sandstone slope, waterworn gravel occurs, the pebbles

[1] Gannett, Henry, Dictionary of altitudes in the United States: U. S. Geol. Survey Bull. 274, pp. 1042–1062, 1906.

[2] Op. cit., p. 130.

of which were derived from the local rock. On the slope below the gravel the surface is covered with loam which has a suggestion of stratification, while above it the soil and subsoil appear to be the product of local rock decomposition. This waterworn gravel of local origin on a steep slope facing the valley probably represents the work of the waves of this lake, perhaps when it stood at its maximum height. This gravel is about 125 feet (aneroid measurement) above the Baraboo River to the north.

DEPOSITS IN THE BARABOO BASIN.

Bordering the moraine front at an elevation about 1,000 feet above sea level is an outwash terrace of stratified sand and gravel one-half mile to 2 miles wide, which slopes gradually westward into the basin, and terminates south of the river against the higher rock slopes on the west, excepting where subsequently cut away by Skillet Creek. North of the river it ends in a steeper marginal slope, dropping from about 960 feet above sea level to the extensive flat which formed the lake bottom. This slope appears to have been the subaqueous front of the terrace where the filling encroached on the deeper waters of the lake. Material of the coarseness of the sand and gravel composing the terrace would not be carried far out into such a lake by waters escaping from the glacial front. The margin of the lake was doubtless crowded back from the immediate vicinity of the ice front as the filling progressed and the terrace was built above the water level. This is another reason for thinking that the elevation of the lake surface was not above 970 or 980 feet. The material exposed beneath the loose sandy soil is sand and gravel with pebbles up to 6 and 8 inches in diameter. Some of the wells penetrate, besides sand and gravel, more or less clay. One well north of the river gave the following log:

Log of A. E. Britten's well in the NE. ¼ sec. 28, T. 12 N., R. 6 E. (Baraboo Township).

	Feet.
Sand and gravel	75
Blue clay and sand	75
Fine gravel at bottom.	
	150

The clay was encountered at about the level of the lake bottom flat farther west, and may represent the extension of the lake clays beneath the coarser outwash material. Gullies near the bridge over Skillet Creek, one-half mile southeast of Kirkwood station, expose beautifully laminated sand and calcareous clay containing scattered pebbles of crystalline rock, and at the old brickyard near the point where the railway crosses the creek there was exposed unstratified outwash material and gravel overlying finely laminated, calcareous clay. About one-half mile west of Lyons a road cut exposes 7 to 8 feet of brownish, calcareous laminated clay with some sand and gravel at the top. About a mile farther northwest a gully near the bridge exposes 4 to 5 feet of sand over reddish, laminated, calcareous clay. About 1½ miles farther west, a test bore at G. E. Hackett's is said to have penetrated sand, blue clay, and reddish clay 60 feet, overlying sandstone. Three test bores within the bend of the river, 1½ miles northeast of North Freedom, penetrated sandy soil, blue clay 80 to 90 feet, and sand to depths of 110, 117, and 125 feet before reaching the sandstone. At Jane Smith's, near by, a filling, mostly of sand and gravel, was penetrated to a depth of 195 feet. Drillings near Kirkwood station penetrated clay and sand to depths of 200 to 250 feet. At the river bend, 1½ miles northeast of North Freedom, a gully in the 20-foot bank exposes sand with some drift pebbles 5 feet, laminated reddish calcareous clay 10 feet, shaly sandstone 5 feet. Two drillings one-half to three-fourths mile east of North Freedom, below the flat, penetrated 230 and 250 feet of filling. Some borings on the flat south of North Freedom are said to have penetrated sand and gravel, others clay and sand, and one only blue clay, to depths of 90 to 237 feet. The record of one of these wells showed clay 100 feet, overlying sand 137 feet; another clay 100 feet, overlying sand, gravel, and bowlders 118 feet. In the part of the plain lying south of the river and west of the railway spur running to the Illinois mine, twenty or more bores concerning which information was obtained penetrated 6 to 138 feet of filling. The maximum depth is even greater than this, for a well just east of the bridge near the mine was drilled by Mr. Erswell 240 feet to sandstone, though this rock rises above the flat in bluffs barely 20 rods away. So far as learned most of the material was clay and sand with gravel and bowlders in some places. William Gunnison's well, one-half mile north of the North Freedom railway bridge, penetrated blue clay 65 feet, loose sand and stones 40 feet, blue clay 10 feet, sand and stones 37 feet. About one-half mile northwest of this place 15 feet of the calcareous clay is exposed in the river bank. It is also slightly exposed at the bend of the river a mile south of Ableman.

Similar fillings extend through the constricted parts of the valley at Ableman and the gorges of the upper narrows of the Baraboo and of Narrows Creek. A generalized section of the filling penetrated by the wells at Ableman, furnished by William and James Lee, well drillers, shows in succession blue clay 14 to 18 feet, sand, blue clay 14 to 18 feet, sand and gravel. The depths of these wells range from 60 to 114 feet.

The occurrence of a gabbro bowlder 6 to 7 inches in diameter,[1] about 50 feet above Narrows Creek, on the south slope near the head of the gorge, is regarded by the present writer as an indication that drift-bearing ice was floated westward through the gorge. Obviously, however, this would occur only rarely and no other erratic bowlders or pebbles are known to have been found in this basin west of the Upper Narrows. This basin of Narrows Creek has likewise a broad flat plain into which the stream has cut 10 to 15 feet. Wells show a filling of 45 to 85 feet. The exposures, however, so far as noted, show no foreign material among the gravels. A section afforded by the creek bank near the bridge 1¼ miles west of the Narrows shows buff sandy loam 5 feet, stratified sand and chert and quartz gravel 3 feet, stratified clayey sand 10 feet. The material appears to be alluvium, though the valley must have been flooded to a depth of 100 feet above the flat.

The Baraboo Valley has not been examined by the writer above Reedsburg. Between this place and the Upper Narrows the stream meanders through a broad flat plain about 1½ miles in width, into whose filling wells have penetrated 60 to 110 feet, showing generally 10 to 40 feet of blue clay or interbedded blue clay and sand, underlain by sand, chert, and gravel. Many of the wells in this basin afford excellent artesian flows from the sand and gravel beneath the clay. An exposure in a creek bank at the bridge near the river bend, 3 miles southeast of Reedsburg, showed the following:

Section of lake beds 3 miles southeast of Reedsburg.

	Feet.
Buff loamy clay, sandy at top	3–6
Stratified sand with bits of sandstone and chert	3–6
Interlaminated blue, sandy, calcareous clay and thin sandy partings, with no pebbles	10

The fact that this laminated clay is highly calcareous is regarded as evidence that it is pulverized rather than decomposed rock and is glacial silt the same as that in the basin below the Narrows.

At the road forks north of the north end of the Upper Narrows 3 feet of well-rounded quartzite gravel is exposed below 2½ feet of buff to reddish clay. This gravel is undoubtedly from decomposition or erosion of the Cambrian basal conglomerate exposed in the slope of the ridge near by. It may have been redeposited by the waters of Lake Baraboo when the flat was submerged.

The question again arises as to what part of this valley filling is to be correlated with outwash from the later Wisconsin glacier. There are not in hand data showing clearly whether or not the lacustrine filling extends eastward beneath the glacial drift in the basin. The large amount of sand in the drift makes it difficult to determine from the available information what part is glacial drift, what glacio-fluvial, and what glacio-lacustrine. Some of the wells encountered much blue clay, which may be in part at least lacustrine; others, as, for example, several along the front ridge of the moraine and those at the Baraboo waterworks, are mostly in sand and gravel. Smith's well, one-half mile east of the Baraboo fair grounds in the SW. ¼ sec. 31, T. 12 N., R. 7 E. (Greenfield Township), penetrated blue clay over sand 76 feet, and blue and white clay 30 feet. The lower clay may be lacustrine. If the Wisconsin Valley to the south was silted up to 780 to 800 feet above sea level before the extension of the later Wisconsin glacier (see p. 192), it seems very probable that the Baraboo basin must have been filled to a corresponding level at the same time.

The following logs of drillings, mostly given from memory by the drillers, show the occurrence of organic remains in the filling of the Baraboo basin between the moraine and the

[1] Weidman, Samuel, The Baraboo iron-bearing district of Wisconsin: Wisconsin Geol. and Nat. Hist. Survey Bull. 5, p. 101, 1904.

Upper Narrows, and some of them seem to indicate quite clearly the occurrence of more than one stage of filling separated by an interval during which marsh muck accumulated. The wood and bones may have been washed into the basin, or the former may have grown in place where found. Black material may also have been washed from the surrounding slopes into the basin at some time when conditions were favorable to removal of the soil, as, for example, when the slopes were largely bare of vegetation. It is not possible to draw very definite conclusions from such indefinite data, but they are at least interesting.

Partial log of well at Henry Hill's, on the outwash plain near the west front of the moraine, 1½ miles northwest of Devils Lake.[1]

	Feet.
Blue clay.	
Sand.	
Black muck	60–70
Sand to 235 feet.	
Cambrian sandstone.	

Partial log of well on the south bank of Baraboo River, 1½ miles west of Lyons.[2]

	Feet.
Drift and other filling	200
Wood and shells at about 660 feet above sea level.	
Rock.	

Partial log of drill hole on flat within Baraboo River bend, 1¼ miles east of North Freedom.[3]

	Feet.
Drift and other filling	160
Bones in sand at 135 feet (about 715 feet above sea level).	
Wood in sand at 150 feet (about 700 feet above sea level).	

Partial log of well at North Freedom creamery.[4]

	Feet.
Blue clay	38
Black muck and sand about 845 feet above sea level.	4
Cambrian sandstone.	

Log of Mr. Pfaff's well on the flat north of the river, 1½ miles northwest of North Freedom.[4]

Blue clay and sand.
Gravel.
Blue clay.
Log of wood and marsh muck.
Blue clay.
Leaves and twigs at 108 feet (about 800 feet above sea level).
Blue clay.
Black soil and roots.
Coarse gravel.
Depth, 114 feet.

Log of well on flat east of Seeley Creek, 2½ miles southwest of North Freedom.[5]

	Feet.
Drift and other filling	240
Wood at about 100 feet down (about 790 feet above sea level).	

Log of Henry Alexander's well on the flat plain, about 2 miles south of Ableman.[4]

	Feet.
Blue clay	14
Quicksand	40
Blue clay	20
Black sand and twigs, about 815 feet above sea level.	20
Quicksand	8
Gravel	6

Log of Mr. Richardson's well, fourth house east of the railway, Ableman.[4]

	Feet.
Sand	80
Rotten twigs, sand, and shells, the latter crumbling when dry, at about 810 feet above sea level.	
Cambrian sandstone.	

DEPOSITS IN THE UPPER WISCONSIN VALLEY.

The blocking of the Wisconsin River valley caused the ponding of the waters west of the ice front over a large part of Adams and Juneau counties and the adjacent parts of some of the neighboring counties, forming the glacial Lake Wisconsin.[6] The occurrence of finely laminated calcareous clay in many places beneath the sandy plain seems to the writer conclusive evidence of the former existence of such a temporary lake. There is no other known source for the calcareous silts than the glacial drift. They are the finer products of the grinding of calcareous sedimentary rock in the glacial mill and were precipitated in quiet water. This clay is certainly not such alluvial material as would be expected from the erosion of the sandstones and crystalline rocks of the upper part of the Wisconsin Valley or from the wash of residuum left by the aerial decomposition of these rocks.

Weidman[7] states that the well water throughout the north-central Wisconsin area (north of the area under discussion) is "soft," owing to the absence of limestone. If this is the case the calcareous element in the drift to the north must be very small and would scarcely furnish calcareous silts to the river in

[1] E. W. Van Akin, driller, Baraboo, informant.
[2] Rodgers, driller, Baraboo, informant.
[3] F. B. Clarke, driller, Baraboo, informant.
[4] William and James Lee, drillers, Ableman, informants.
[5] Erswell, former occupant, informant.
[6] Geology of Wisconsin, vol. 1, p. 285, 1883.
[7] Weidman, Samuel, Geology of north-central Wisconsin: Wisconsin Geol. and Nat. Hist. Survey Bull. 16, p. 664, 1907.

any considerable amounts. Weidman[1] states that only one deposit of marl is known to occur in that area—at Lime Lake, 5 miles southwest of Amherst in the terminal moraine of the Green Bay Glacier. Most of the drift exposed in the Johnstown moraine north of the Baraboo Bluffs is sand, but not uncommonly some clay is included. A large part of the material has been assorted by water action and the finer silts removed. This part is probably represented in the laminated lake clays to the west. Estimates based on the pebbles found at 12 exposures in the moraine north of the Baraboo Bluffs, one of them on the north line of Waushara County, showed an average of 43.3 per cent to be from limestone. This percentage may not be representative of all the material of the moraine, yet it would seem to indicate that the glacial drift was an adequate source for the calcareous lacustrine silt and that the presence of the silt is good evidence of the former existence of the lake.

Northward from the north range of the Baraboo quartzite, through northern Sauk, northwestern Columbia, eastern Adams, and western Waushara counties the terminal moraine is bordered by a flat sandy plain sloping gently westward. With some variations the elevation at the morainal front increases gradually northward from about 990 feet at the south line of Delton Township to about 1,100 feet above sea level in places in western Waushara County.

In the southern part of Delton Township, over the ancient valley of Dell Creek, this terrace has a maximum width of 4 miles. Northward over the former divide between this valley and the Wisconsin the terrace narrows to a minimum width of one-fourth mile, partly in consequence of erosion by Dell Creek and its tributary drainage in cutting its postglacial valley across the divide. From an elevation of 980 to 990 feet above sea level at the moraine front the terrace slopes very gently westward to an elevation of about 960 feet and thence drops more sharply to the bordering erosion lines. This terrace is believed to have been developed in the margin of glacial Lake Wisconsin. Within 2 miles of the moraine gullies expose, beneath the sandy soil, sand and gravel with fine to 4 and 6 inch pebbles, largely quartzite with some limestone. Farther west, the amount of gravel becomes very small, the material being almost entirely sand except where clay is exposed. The waters ponded in Dell Creek valley, except where they connected with the main glacial lake across the divide in the vicinity of Delton and with Baraboo Lake in northwestern Excelsior Township, formed a separate lake, into which the outwash material was swept. The coarseness of the material and the extent of the terrace above an elevation of 960 feet lead to the suggestion that the level of the lake, at least while the higher part of the terrace was being formed, may not have been more than 960 feet above sea level, for it is difficult to understand how such material could be swept 4 miles into a body of water standing in this valley, as it must have been if the water stood so high as to extend clear to the morainal front, at a level 980 to 1,000 feet above sea level. Wells on this terrace are reported to penetrate principally sand and gravel to depths of 60 to 136 feet. Numerous crystalline bowlders occur scattered through the basin west of the limit of the outwash terrace, but the writer has found none above the 980-foot level, though some were very close to it. These bowlders, which are not associated with any other glacial material, are believed to have been carried out by floating ice, before the outwash terrace was entirely completed and possibly at a stage when the water level stood at or near 1,000 feet above sea level.

That this basin was occupied by a lake seems evident from the topographic situation, the presence of these scattered bowlders, and the occurrence of laminated clay similar to that exposed in the Baraboo basin. Thicknesses of 5 to 15 feet of this clay were seen at four places, 880 to 920 feet above sea level, within 1½ miles of the head of Mirror Lake, where streamlets had cut through or near the margin of the outwash terrace.

The following mechanical and chemical analyses of a sample of the clay exposed in the ravine in the NW. ¼ sec. 6, T. 12 N., R. 6 E. (Delton Township), show the size of the particles and their composition. The mechanical analysis was made in the Bureau of Soils, U. S. Department of Agriculture, through the courtesy of J. A. Bonsteel, at the request of the writer.

[1] Op. cit., p. 654.

Mechanical analysis of glacial lacustrine clay from sec. 6, T. 12 N., R. 6 E. (Delton Township), Sauk County, Wis.

	Size in millimeters.	Per cent.
Fine gravel	2 to 1	0.0
Coarse sand	1 to 0.5	.1
Medium sand	0.5 to 0.25	.0
Fine sand	0.25 to 0.1	.4
Very fine sand	0.1 to 0.05	3.1
Coarse silt	0.05 to ?	13.9
Fine silt	? to 0.005	35.5
Clay	0.005 to 0	46.9

The chemical analysis was made in the laboratory of the United States Geological Survey by W. T. Schaller.

Chemical analysis of glacial lacustrine clay from sec. 6, T. 12 N., R. 6 E. (Delton Township), Sauk County, Wis.

SiO_2	40.56
Al_2O_3	14.91
TiO_3	.57
Fe_2O_3 (total iron)	4.32
MgO	2.63
CaO	12.11
K_2O	2.57
Na_2O	1.59
CO_2	2.24
H_2O	18.30
	99.80

Comparison of the results of the chemical analysis with similar analyses of the fine rock flour of the buff and red glacial tills (p. 323) shows their similarity in composition and supports the interpretation that this lacustrine clay was derived from the glacial drift. The mechanical analysis shows the remarkable comminution of the particles, which must have been precipitated in rather deep and quiet waters. Later this clay was partly buried by the sands of the advancing outwash terrace front.

Nothing simulating lake-shore phenomena was noted in this basin except at one place where the road crosses the hill three-fourths mile south of Delton. At this place, at an elevation of about 1,000 feet above sea level, the following section was exposed:

Possible lake shore deposits three-fourths of a mile south of Delton, Wis.

	Feet.
Buff to brown loamy clay with included cherts and occasional crystalline pebbles	1–3
Coarse sandstone gravel	2
Cross-bedded sand with some fine crystalline gravel	2

The larger part of the basin in Dellona and Excelsior townships, Sauk County, never having been cut below the present level, has a gently undulating surface with sandy soil and numerous exposures of sandstone.

North and east of the river the surface of the sandstone beneath the plain is evidently very uneven and in places slopes eastward; but the outwash material, together with whatever there was of earlier filling, has built upon it a nearly flat plain sloping westward from the morainal front. At several places within a few miles north and northeast of Kilbourn hills of sandstone rise above the level of this terrace. Between 10 and 20 miles north of Kilbourn a series of bold sandstone bluffs, possibly the remnants of an ancient divide, rise above the sandy plain. Still farther north in the towns of Preston, Adams, Richfield, and Lincoln, Adams County, similar sandstone bluffs overlook the plain. These may mark a second divide which extended eastward through T. 17 N., R. 8 E. (Springfield Township), into Newton Township, and which was partly overridden by the glacier. The higher of these bold bluffs must have stood as islands in the lake. The outwash terrace, which has been partly cut away by erosion in the vicinity of The Dells, broadens northward and, as stated above, the elevation gradually increases, rising above what was the level of glacial Lake Wisconsin. If the lake at first extended up to the morainal front it was gradually crowded westward by the filling of sand and gravel washed out from the glacial front.

Throughout most of Adams County north of The Dells and Briggsville quadrangles accurate elevations are not at hand, but from barometric readings made by the writer it appears that in places the east margin of the lake finally must have been as much as 10 miles west of the moraine. In the area below the level of the lake extensive marsh and swamp tracts still persist.

Most of the material exposed at the surface of the outwash terrace and in the ravines is sand. At some places a little gravel, generally of cherts and crystalline pebbles with no limestone, is seen. Gravels along the railway near Kilbourn, however, show a percentage of limestone pebbles corresponding to that found in the morainal drift. Wells on the outwash terrace penetrate mostly sand with some gravel to depths of 50 to 160 feet or more. Many wells in Newport and Dell Prairie townships which go down to levels 880 to 930 feet above sea level encounter a bed of clay 5 to 25 feet in thickness.

Highly calcareous, laminated, reddish clay, identical in character with that in Dell Creek valley and probably the continuation of that reached by the wells in the outwash terrace, is exposed at several places as far north as Friendship [1] and is reported from beneath the sandy soil at many places farther north.

This clay was observed by the writer in a railway cut near the "Station 1 mile" post southeast of Kilbourn and in an excavation at the top of the hill on the west side of the river at the forks of the road a mile south of the Kilbourn bridge, in the SE. ¼ sec. 8, T. 13 N., R. 6 E. (Delton Township). At the exposure southeast of Kilbourn there was the following section:

Deposits at "Station 1 mile" post southeast of Kilbourn, Wis.

	Feet.
Buff noncalcareous clay (loess)	5–8
Sand and glacial gravel (outwash)	3–4
Reddish, highly calcareous, laminated clay (glaciolacustrine)	3–4
Sand	?

This section is barely one-half mile from the front of the moraine and shows the deposition of fine stoneless silt prior to the deposition of the outwash gravels. It shows, however, no evidence of any interval of exposure of the clay prior to the deposition of the gravel. The excavation west of the river shows what might be regarded as evidence of an interval. It exposes, above sandstone, 6 to 8 feet of laminated calcareous clay, cut by three small gullies 2 to 3 feet deep, which are filled with sand and gravel. The whole exposure is also thinly covered with sand and gravel. In most of the section the clay is oxidized and leached to a depth of 2½ to 3 feet, and beneath the gullies to a depth of 5 feet (the bottom of the clay); also the laminæ sag beneath the gullies as though due to settling in consequence of deeper and more thorough leaching. A few crystalline bowlders occur in the excavation, perhaps having fallen from the surface. Not far away a crystalline bowlder 10 feet long lies on the surface. The rest of the clay and of the outwash gravel in this vicinity west of the river appear to have been removed by erosion.

[1] Irving, R. D., Geology of central Wisconsin, vol. 3, p. 610, 1877.

The laminated clay was observed in an excavation near the road at the county line about a mile northeast of Kilbourn and again beside the road about 100 rods north of Witches Gulch. Ravines cutting the north slope of the creek valley a mile east of Plainfield expose 10 to 15 feet of reddish clay interlaminated in its lower part with thin layers of sand and underlain by sand containing a few crystalline and chert pebbles. This clay is calcareous below 4 or 5 feet from the surface.

In the vicinity of Easton a bed of laminated red clay has been cut into, if not through, by White Creek and is said to have been penetrated by wells to a depth of 25 to 40 feet. There is good reason for thinking that this bed is continuous north and south through much of Adams County. Wherever exposed it lies 920 to 980 feet (barometric) above sea level. Where the present land surface is below this level the clay may have been removed by erosion. Where it is higher, except where the sandstone rises as mounds or bluffs, it is covered with sand and a little gravel. This deposit of clay is not known to extend east of Adams County or beneath the moraine. In many exposures the lamination is obscured to depths of 3 feet or so and the calcium carbonate removed by leaching to depths of 5 feet or more. The depth of the leaching has given rise to the question whether the clay may not have been deposited at an earlier stage of glaciation.

One of the best exposures of this clay is in the banks of the creek at Friendship, where an excavation a short distance northwest of the bridge gave the following section:

Lacustrine deposits at Friendship, Wis.

	Feet.
Sand with a few pebbles at the bottom	3
Calcareous red clay (laminæ obscured)	2½
Laminated calcareous red clay	3

The upper part of the clay bed beneath the sand suggested the presence of a soil horizon, but the signs were too indefinite to permit certain identification.

Similar clay was observed at several places farther north in the towns of Preston and Strongs Prairie and at one point in the town of Rome within 3 miles of the north line of Adams County.

At Necedah, a few miles northwest of the area under discussion, in an excavation just west of the south quartzite hill and south of the line of the Chicago & Northwestern Railway, 2 to 2½ feet of dense reddish clay was exposed beneath 2 to 2½ feet of sand. This clay is dense, massive, jointed, unstratified, and noncalcareous. Whether it is laminated and calcareous at greater depths is not known. Clay is also reported as underlying sand in places, at least, beneath the surrounding plain.

A sample of calcareous, reddish, laminated clay identical in character with that observed in Adams County, given to the writer by Mr. Lapham, of the Department of Agriculture, was obtained from a bed of clay observed in 1910 by Mr. Lapham and A. R. Whitson a mile or two east of Mauston, Juneau County, near Lemonweir River, not far west of the area under discussion.

The occurrence, so widely distributed, of these calcareous laminated clays in the valley of Wisconsin River appears to the writer as conclusive evidence of the existence of a lake when the ice front occupied the terminal moraine. Scattered crystalline bowlders were also found west of the river in the southern part of this basin. These are numerous within 3 or 4 miles of Kilbourn, but farther northwest they are rare, though half a dozen were noted on the sandy plains about Lyndon. They are believed to have been dropped from bergs or floes of ice floated out from the glacier. It is significant that they have not been noted farther north, where the lake waters may not have reached the glacial front.

The writer's observations developed nothing indicating that this clay was deposited prior to the maximum extension of the later Wisconsin glacier. It is not exposed in the moraine at the railway cut southeast of Kilbourn; and (so far as could be ascertained from well owners and from Charles Martin, who has done a large part of the drilling from the river northward into Jackson Township) it is not found beneath the loose morainal deposits in the wells, on the moraine, though many of these penetrate to levels lower than that at which the clay to the west occurs.

Although information concerning the wells is not entirely satisfactory there seems to be no proof that the clay is anything else than glacial silt deposited in glacial Lake Wisconsin when the ice front stood at the moraine and blocked the valley. It was probably first laid down in northern Sauk County, northwestern Columbia County, and part of eastern Adams County, when the water was deep clear up to the ice front. As the water near the ice front shallowed from the deposition of sand, sand and gravel were swept farther and farther out from the moraine, covering the silt and extending the subaqueous terrace. When the terrace rose above the lake level shifting streams of glacial water carried the material to the terrace front, extending it and crowding back the lake waters. The scattered bowlders west of the river were probably carried out by floating ice while yet the lake extended to the moraine. The dissection of the terrace and its partial removal in the vicinity of The Dells is the result of subsequent erosion when the ice was melted away so as to allow the lake to drain across the moraine and around the east end of the Baraboo Bluffs. After the lakes were thus drained Baraboo River, Dell Creek, and Wisconsin River began the excavation of their new channels, cutting through the moraines, outwash, and lake beds and into the underlying rock, wherever it was encountered. Reference to Plate II (in pocket) shows how far the present courses of these streams diverge from those occupied in preglacial time. The comparative recency, geologically speaking, of the disappearance of the ice; the rapid downcutting in the friable sandstone by Wisconsin River, Dell Creek, and their tributaries, which did not afford opportunity for the widening of the valley and the reduction of the side slopes; and the differential weathering of the uneven-textured sandstone—all have contributed to the picturesqueness and beauty of The Dells and tributary gorges. (See Pl. V, *B*, p. 32.)

LAKE MICHIGAN GLACIER.

TERMINAL MORAINES.

The moraines of the Lake Michigan Glacier that seem to correlate with the Johnstown moraine of the Green Bay Glacier are embraced in the Valparaiso and Kalamazoo morainic systems. (See Pl. XXIII, p. 208.) The Kalamazoo has not been definitely distinguished in southeastern Wisconsin and northeastern Illinois, so that references in this paper are principally to the Valparaiso system.

In western Racine and Kenosha counties the Valparaiso system gives off on the west a series of broad curving branches that connect with the Kettle interlobate moraine of the Lake Michigan and Green Bay glaciers and mark the successive positions of the margin of the Delavan lobe of the Lake Michigan Glacier, which projected from the angle made by the converging fronts of the two great glaciers. As the northward continuation of the Valparaiso system is traced through Kenosha and Racine counties it is found to decrease in breadth and in bulk as the successive branches are given off on the west, until finally it becomes very indefinite and very poorly marked. From this relation it appears that the main front of the glacier continued at the broad morainal belt bordering Fox River in Kenosha County and for some distance to the southward during the whole time of the extension of the Delavan lobe and of its melting back to eastern Waukesha County. The moraines of the Delavan lobe and the Kettle interlobate moraine with which they connect are thus to be considered the correlatives and direct continuations of the Valparaiso morainic system of southern Kenosha County. For convenience of reference three of the moraines of the Delavan lobe have been named Genoa, Darien, and Elkhorn, respectively.

VALPARAISO MORAINIC SYSTEM.

The Valparaiso morainic system has a breadth of nearly 9 miles where it enters Kenosha County, Wis., from the south, extending from southeastern Randall Township on the west to southwestern Bristol Township on the east. From the State line northward through Kenosha and Racine counties it is divided into two more or less distinct belts by Fox River and bordering flats. In Salem and Bristol townships it is marked by broader undulations and by scattered depressions which have abrupt ice-contact slopes and are occupied by lakelets and marshes. In T. 2 N., R. 20 E. (Brighton Township) its surface is more hilly and shows distinctively morainal features only in the west. About as far north as Burlington the belts on either side of Fox River are marked by more or less disconnected groups of kames in the form of bulky ridges pitted with kettle holes and by alternate low marshy tracts and flats underlain by outwashed sands and gravels. The belt on the west side of the river merges with the Genoa, Darien, and Elkhorn moraines of the Delavan lobe.

In the town of Rochester the belt west of the river is contracted to a more definite moraine strongly marked by kames and kettle holes, but in Waterford and western Norway townships (T. 4 N., Rs. 19 and 20 E.) the whole morainic system, though considerably pitted, spreads out more indefinitely, merging with morainal deposits of the Delavan lobe on the west and nowhere presenting any very definite relief. Thence northward for about 4½ miles from Tishigan Lake the moraine is very indistinct.

The several moraines of the Delavan lobe (branches of the Valparaiso morainic system) are described below in connection with the correlated moraines of the Green Bay Glacier.

GENOA MORAINE.

The Genoa moraine should perhaps be considered a part of the Darien moraine, from which it branches to the west and southeast in Lynn and Walworth townships and becomes the outermost of the terminal moraines of the Delavan lobe. Between Richmond and Walworth the Darien moraine is the outermost, having continued to be occupied by the ice after its south front had melted back from the Genoa moraine between Walworth and Genoa Junction. Except within 3 miles west of Genoa Junction the Genoa moraine has a weak and rather equivocal development, especially where it branches from the Darien moraine. At this place the Marengo Ridge, the outermost of the terminal moraines of the early Wisconsin glaciers entering Wisconsin from the south, ends in a long north slope dropping into the preglacial Troy Valley at its junction with the preglacial Geneva Valley. A mile southeast of the village of Walworth, separated from the Darien moraine by a slight interval, a narrow and well-defined belt of morainal topography which borders the east margin of Big Foot Prairie may be traced up the slope to the south and thence southward as the crest of Marengo Ridge. A short distance east of the north extremity of this belt a milder morainal belt (the Genoa), marked by sags and swells and by some gravel knolls and kettle holes, separates from the main front of the Darien moraine south of the western end of Lake Geneva and may be traced with some discontinuity southeastward across the State line and thence eastward and northeastward into Wisconsin again along the south border of the marshy valley of Nippersink Creek, which cuts it one-half mile north of Genoa Junction. From the second crossing of the State line to the valley of the Nippersink Creek near Genoa Junction, this Genoa moraine is strongly developed. The abrupt ice-contact face rises 60 to 80 feet above the marshy tracts on the north to a crest broken by abrupt knolls and ridges of gravel alternating with kettles, many of which are large and deep.

East of Nippersink Creek the moraine may be traced for a mile by a narrow gravel ridge pitted with kettles which forms the crest of a broad ridge, apparently of till.

Northeastward into the town of Wheatland and thence southward through the town of Randall (Tps. 2 and 1, R. 19 E.) the converging Genoa and Valparaiso moraines are much alike in character. The whole belt is interlaced with irregular depressed areas, mostly marshy, some containing tamarack swamps and two occupied by Power and Lilly lakes. Within these depressions, surrounding them, or alternating with them are irregular hills, ridges, and hummocky deposits of gravel, many of which show reliefs of 60 to 100 feet.

The development of the Genoa moraine is so slight in some parts that positive demonstration can not be claimed for the correlation here given, yet after careful study of the area the writer feels confident that it can not be far from correct. There can be no question that the strongly developed part of the moraine within 3 miles of Genoa Junction on the west, with its bordering deposit of outwash gravels, was formed at the south front of an ice sheet, and the most natural correlation makes it the deposit of the Delavan lobe during the extension of its south front beyond the main terminal moraine.

OUTWASH DEPOSITS.

Throughout the glacial history of this part of Wisconsin and especially during the later Wisconsin glaciation the disposition of the water resulting from the melting of the ice was an important factor in developing the area. The glacial waters washed out great quantities of material from the drift transported by the glaciers, assorted it, and made extensive deposits beyond the limits of the ice. Although it is not possible to determine very definitely which of the deposits bordering the outer moraines pertain to earlier deposition and which to that from the later Wisconsin glaciers it seems clear that a considerable amount of them must be referred to the later stage.

Bordering the converging Genoa and Valparaiso moraines in the town of Randall are outwash deposits which decline toward the depression occupied by Twin Lakes. The gravel deposits are generally so well coated with clay and grade so smoothly on the one hand into the moraine and on the other into gently undulating till areas that their exact limits are not easily determined and can be shown on the map only approximately. In the pit of the Chicago & Northwestern Railway just west of Twin Lakes station 30 to 35 feet of nearly horizontally bedded gravels overlain by 1 to 3 feet of clay are well exposed.

From the valley of Nippersink Creek at Genoa Junction nearly to Hebron, Ill., the Genoa moraine is bordered by an extensive deposit of outwash sand and gravel, which in many places is exposed beneath a thin coating of clay.

ABANDONMENT OF THE GENOA MORAINE.

The deposition of the Genoa moraine and of the accompanying outwash deposits seems to have been followed by the melting away of 3 or 4 miles of the southern border of the Delavan lobe, so that the south front of the ice withdrew to the Darien moraine between southwestern Racine County and the head of Lake Geneva. Elsewhere the ice margins appear to have continued at their outer moraines. Between the villages of Walworth and Richmond the southwest front of the Delavan lobe continued at the Darien moraine. From Richmond northeastward the fronts of the Green Bay and Lake Michigan glaciers were still in conjunction along the line of the Kettle interlobate moraine; and the south front of the Green Bay Glacier stood at the outer, or Johnstown, moraine. The west front of the main Lake Michigan Glacier still occupied the morainal belt west of Fox River in western Kenosha County, though the angle of junction with the south front of the Delavan lobe was shifted northward nearly to the southwest corner of Racine County.

DARIEN MORAINE.

The principal terminal moraine of the Delavan lobe is the Darien moraine, so designated from the fact that the village of Darien in western Walworth County stands on its outer margin near the southwestern extremity of the lobe.

TOPOGRAPHY.

The Darien moraine varies in width from 1 to 3½ miles, its slopes usually presenting very moderate relief. Between Richmond and a point opposite the head of Delavan Lake the relief is only 20 to 40 feet, except where erosion of the bordering outwash deposit has increased it to 60 feet. Near the village of Walworth it reaches 100 feet, and south of Lake Geneva the long slope rises 100 to 150 feet above the low area at the south. From Lake Geneva to its junction with the Valparaiso morainic system, south of Burlington, there is no regular outer slope, the deposit being broken by irregular, winding, marshy depressions, from which the immediate slopes rise 20 to 80 feet.

The relief of the inner slope is even more variable. Where bordered by Turtle Creek the relief of 60 to 110 feet is in part due to the subsequent deepening of this valley. From Delavan to Lake Geneva, except in the Delavan Lake basin and in small eroded valleys on the north and south, there is no definite inner slope and only 20 to 60 feet relief. At several places the terminal-moraine topography grades almost imperceptibly into that of the ground moraine. The bed of Delavan Lake lies 140 to 150 feet below the higher points opposite its head. By far the greatest relief is found in the slopes of the Lake Geneva basin. In the western part, between Cooks Camp and Camp Collie, the lake reaches its greatest depth, 142 feet. The elevation of the bottom here is 719 feet above the sea, or 400 feet lower than the morainal crest 1½ miles southeast. Between the foot of the lake and Burlington the inner margin of the moraine has, in part, a somewhat regular front, but elsewhere it is very irregular. Here the higher parts are near the inner margin, and abrupt reliefs of 40 to 120 feet occur. Much of the irregularity of this inner margin occurs at the junction of the Elkhorn and Darien moraines.

From Richmond to Lake Geneva the prevailing surface contours are of the sag-and-swell type. The reliefs are very slight in the inner part of the belt but become somewhat stronger near the outer front. Some parts of the outer half are closely pitted with kettles 10 to 40 feet in depth and carry some gravel knolls 15 to 40 feet in height. South of Lake Geneva some slight kettles are found, but for the most part the surface of the bulky ridge is marked by gentle undulations. From Lake Geneva to Burlington the topography is much more diversified. The morainal belt is interrupted by very irregular, marshy depressions with abrupt surrounding slopes. The inner part of the belt has generally a strongly marked knob and kettle topography, in which abrupt conical knolls and narrow sinuous ridges of gravel alternate closely with deep round pits and narrow winding depressions and 30° slopes and 40 to 100 foot reliefs are not uncommon. In some parts these combine to form a wilderness of humps and hollows. Toward the outer margins of the moraine the topography becomes more subdued, the relief decreases, and, except about the margins of the marshy depressions, the knobs and kettles give place to sags and swells and gentle undulations.

A part of the irregular depressions unite to form two continuous valleys which lead from the marshes along White River within the moraine to the marshy valley of Nippersink Creek within the Genoa moraine and thence to the break in the moraine at Genoa Junction, where a large part of the glacial waters found an outlet.

At the head of the Geneva basin, at an elevation of 1,000 feet, or 140 feet above the level of the lake, there is a sag in the Darien moraine, but neither the sag nor the surface of the outwash plain gives evidence of the passage of much water from the lake basin. Two miles north of the village of Darien the moraine is cut by a broad, flat-bottomed valley one-half to 1½ miles wide and 80 to 100 feet below the adjacent parts of the moraine, through which winds Turtle Creek. This valley, which will be referred to as the Turtle outlet, was eroded by glacial waters subsequent to the withdrawal of the ice from this moraine. Kettle holes occurring in the north slope to within 40 or 50 feet of the valley bottom indicate that a sag in the moraine at this point determined the location of the valley.

STRUCTURE AND COMPOSITION.

So far as can be determined from the surface exposures and from the records of wells ranging in depth from 30 to 250 feet, the moraine between Richmond and Lake Geneva consists principally of sand and gravel. At many places on the knolls the gravels are exposed at the surface, but usually they are covered by a buff, stony clay generally ranging in thickness from 6 inches to 5 feet but in places reaching 10 to 30 feet. In 1915 a deep well was drilled for the Bradley Knitting Co. at Delavan, near the inner margin of the moraine. The log of this well, furnished the writer by F. T. Thwaites, who examined the samples, shows the following deposits overlying the Galena dolomite:

Partial log of Bradley well, Delavan, Wis.

	Feet.
Gravel, fine glacial	30
Glacial till, brownish to gray; with bowlders	290
Sand, coarse, gray, limy	80
Gravel, coarse, with streaks of clay (till?)	15
Bowlders (?) of limestone [possibly bedrock]	20
Quicksand, gray (in cave?)	4
	439

Of this great thickness of drift filling the preglacial Troy Valley, perhaps not more than the upper 30 feet of gravel is really to be correlated with the formation of the Darien moraine. Possibly some of the upper part of the thick bed of till was also deposited at this stage, but the bulk of it may be older.

The best exposure of the structure of the moraine is in an excavation in the bluff at Fontana, where 35 or 40 feet of drift was at one time exposed. At the top was 1 to 5 feet of buff stony clay, below which were gravels, stratified in nearly horizontal layers. In the upper part most of the stones were 1 to 3 inches in diameter, but lower down the material became coarser and at the bottom bowlders 1 to 3 feet in diameter were not uncommon.

South of Lake Geneva numerous exposures show gravel below the subsoil, but the bulky ridge appears from well records to be principally of clay till. At Silas Ingalls's place, near the highest part of the crest, a well was drilled to a depth of 329 feet, of which 311 feet was said to be solid clay, without reaching rock. J. C. Green, of Beloit, informed the writer that a well which he drilled at the Harvard Camp, about 75 feet above the lake, penetrated 160 feet of solid blue clay and 80 feet of soft sticky material, probably "Cincinnati" shale. At G. C. Walker's, near the east end of the lake, a well penetrated 163 feet of clay and 17 feet of sand and gravel.

In Bloomfield and Lyons townships some of the wells penetrate considerable clay as well as gravel. One well in western Burlington Township penetrated, in succession, clay, gravel, quicksand, hardpan, and sand, reaching limestone at 154 feet. Another, a mile west of the city of Burlington, reached rock below 40 feet of gravel.

At most of the exposures between Lake Geneva and Burlington the morainal drift consists of fairly well rounded pebbles and cobblestones, most of them less than 4 inches in diameter, though at many places grading upward to bowlders measuring 2 or more feet. With the gravel there is usually coarse sand, and several exposures show layers of till interbedded with the gravels. Except on the steeper slopes the gravels are generally well covered by several feet of loamy clay, and where the topography is not too rough the area is mostly under cultivation.

LITHOLOGIC COMPOSITION.

Estimates of the lithologic composition of the coarser material of the drift, made at 29 different exposures along the Darien moraine, show very strikingly the predominant local character of the drift. South of the interlobate angle in T. 3 N., R. 15 E. (Richmond Township), 44 to 75 per cent (average nearly 60 per cent) of the pebbles in the drift were of Niagara dolomite. In the eastern part of Walworth Township, 75 to 88 per cent of the pebbles were from this formation. In Bloomfield and Lyons townships, where the Niagara dolomite underlies the drift, the percentage ranges from 80 to 90 per cent. There is generally present in this area a certain percentage of dense, buff limestone, closely resembling the Trenton, but whether it is really from this formation is not certain. The exposure of the Trenton beds in the bottom of the Troy Valley might afford opportunity for a small contribution to the drift of this moraine. The scarcity of material which can be identified as from the "Cincinnati" shale is probably due to the soft and friable nature of the shale, whose principal contribution to the drift would be in finer material rather than in the pebbles on which the estimates were made. Foreign material, crystallines, sandstones, and quartzites averaged 15 to 16 per cent and nowhere constituted more than 25 per cent of the material examined.

KETTLE INTERLOBATE MORAINE.

GENERAL FEATURES.

Extending north-northeast from the vicinity of Richmond in western Walworth County is the great Kettle interlobate moraine, formed by the commingling of the marginal deposits of the Green Bay and Lake Michigan glaciers.

In 1877, in setting forth the results of his studies of this moraine, Chamberlin made the following introductory statement: [1]

> The term "Potash Kettle Range" has been popularly used to designate an extensive series of drift hills and ridges in eastern Wisconsin, whose full extent and relationship were unknown previous to the investigations of the present survey, and concerning the true nature and origin of which diverse opinions have been held. As the term "potash" has no special significance in this connection, it will be discarded.

Concluding his description he wrote:

> The foregoing facts gather themselves into a mass of evidence whose force is altogether irresistible. The Kettle Range is evidently a gigantic moraine. The main range from Kewaunee County to Walworth County marks the westward limit of the glacier that occupied the basin of Lake Michigan and the eastern limit of the one that plowed through the Green Bay valley. The branch that extends southward into Illinois is the continuation of the terminal moraine of the Lake Michigan Glacier. The branch that recurves through the northern part of Rock County and thence northward is the terminal moraine of the Green Bay Glacier upon that side.

Concerning the name to be applied he wrote as follows: [2]

> That portion of the moraine which lay between and was formed by the joint action of the Green Bay and Lake Michigan glaciers constitutes a succession of irregular hills and ridges, locally known as the Kettle Range from the peculiar depressions which characterize it. As this was the first portion to receive systematic investigation and a specific determination of the true nature and method of its formation, and as this moraine will need a specific name to distinguish it from other accumulations, the term Kettle moraine may fittingly be applied to it.

Concerning the wider application of this name he says in a footnote, in part:

> It is proposed to apply the name Kettle moraine to the outermost member [of the several ridges of the morainal belt] when clearly distinguishable. The Kettle moraine, therefore, designates the morainic ridge produced by the extreme advance of later glaciation.

[1] Geology of Wisconsin, vol. 2, p. 205, 1877.
[2] Idem, vol. 1, p. 275, 1883.

Concerning the distinctively interlobate character of this moraine he wrote: [3]

> This ridged belt of drift is a true terminal moraine, formed of the heterogeneous material accumulated at the margin of the ice and plowed up before it at the time of its greatest advance. Those portions that lay in such a singular way between two adjacent glacial lobes have some likeness to a medial moraine, but are not such in any proper sense, for the true medial moraine consists of superficial matter borne passively on the surface of a glacier, having been formed by the junction of lateral moraines in the union and coalescence of two glaciers, which then move forward as one, the moraine lying longitudinally to the glacier and parallel to its motion. But, on the contrary, the intermediate portions of the Kettle moraine lie along the face of two approaching ice sheets, which may have met and antagonized each other to some extent but did not coalesce, and furthermore they lie transverse to the glacial motion and are strictly marginal and are, in real nature, terminal moraines, differing from other portions simply in being formed by two glaciers pushing from opposite directions. We propose for such portions, on account of this peculiarity, the special designation, interlobate or intermediate moraines.

This great Kettle interlobate moraine is the master topographic feature of the whole series of glacial deposits in eastern Wisconsin. It was this which first attracted the attention of early explorers and led eventually to the refinement of glacial studies of the present day throughout this whole region. The reader should not lose sight of its preeminence while perusing the mass of details of its description and interpretation, which seem to the writer to be necessary to the delineation of the relations of the two collaborating glaciers. The present writer's studies have led him to interpret the final configuration of the interlobate moraine in its several parts, the relations of the several component ridges and the associated gravel terraces, and the relations of the several marginal moraines which branch off at intervals on either side from the great central trunk as produced in the main after the two glaciers had reached their maximum extension. The margins of the glaciers were contracted by intermittent stages of melting, which probably alternated with stages of renewed growth. During the latter the ice fronts readvanced to the successive lines marked by the marginal morainal deposits. It was the conditions of drainage and of deposition in and near the reentrant angles formed by the converging ice fronts in the successive positions which deter-

[3] Idem, p. 276.

mined the final disposition and configuration of the several deposits.

It is these phenomena which the writer has endeavored to discuss at their several appropriate places. In doing this he of course lays himself open to the just criticism of "disevaluation, because the details required in the description of the little things obscure the value of the great things." The big thing, as Chamberlin has so graphically shown in his descriptions, is the great interlobate moraine as such. The little things are the obscure and discontinuous belts of marginal deposits branching off from either side of the great trunk and marking the several stages of the glacial retreat. These several morainal belts, if such ill-defined deposits may properly be so designated, seem to the writer to be of sufficient importance, however, to merit the somewhat extended treatment given in this present report. As compared with the great interlobate moraine the minor marginal moraines are topographically so insignificant that they appear to have wholly escaped the notice of the earliest observers. Even the first tracings of the outer terminal moraines around the ends of the Green Bay, Delavan, and Lake Michigan lobes by Chamberlin were received with skepticism. There is difficulty in giving a proper cartographic expression of the relative topographic values of these several moraines when color patterns are used such as those on the map (Pl. III, in pocket), because a moraine shown only as a narrow belt in places may in reality be of much greater bulk and importance than one which is spread over a considerably larger area.

The Kettle interlobate moraine, extending from Walworth County in a north-northeasterly direction to and beyond the limits of the area under discussion, is the great master feature of the whole series of glacial deposits in eastern Wisconsin. Prior to and including the time of the maximum extension of the later Wisconsin glaciers accumulation may be regarded as having taken place simultaneously along the whole extent of this interlobate belt, and it may be that the larger part of the drift piled up in this great moraine was deposited under these strictly interlobate conditions rather than under the conditions which pertained when the diverging ice fronts occupied the successive recessional positions marked by the several later frontal moraines.

The trend of striæ and of drumlins shows that the ice currents were directly opposed head-on. From end to end along this belt the action was that of two independent glaciers. Nowhere within this area is there any evidence that the ice of the two glaciers became confluent along their adjacent margins like tributary streams. The ice did not move parallel to the trend of the interlobate moraine except miles away in the axial portions of the two glaciers. It is the writer's opinion that even at later stages strictly interlobate deposition continued north of the apex of the interlobate angle which was open a few miles more or less between the diverging ice fronts. In the open angle the conditions of deposition were probably somewhat different, partaking more of the glacio-fluvial type than between the opposed glacial margins farther north.

METHOD OF DESCRIPTION.

It would be difficult, even if desirable, to separate the results of deposition under the several conditions along this belt for the purposes of description. In the following discussion, therefore, the writer has described the several parts of the moraine associating the descriptions with those of the correlative moraines and outwash deposits which marked the several stages of the waning ice lobes.

The description of that part of the moraine in Richmond Township and eastern Whitewater Township follows immediately (see pp. 237–238), being correlated with the Darien and Johnstown moraines. The part extending thence northeastward through Lagrange Township is treated later (pp. 259, 263) as part of the Milton moraine. The part between Lagrange and Wales is discussed as interlobate, associated in its formation with the Milton and Elkhorn moraines. (See pp. 269–270.) The part between Wales and the town of Kewaskum in northern Washington County is described on page 280, its final deposition being considered to be contemporaneous with the formation of the Lake Mills morainic system of the Green Bay Glacier and the associated moraines of the Lake Michigan Glacier. The part extending from the vicinity of Kewaskum northeastward to the overlapping red till in southern Manitowoc County is described on pages 308–309 as being correlated with the later marginal moraines of the Green Bay Glacier and with the

Lake Border morainic system of the Lake Michigan Glacier. One desiring a knowledge of the great Kettle moraine as a unit of prime importance should read together the descriptions of the several parts, as noted above. One desiring the writer's ideas of the conditions pertaining during the final stages of the development of this great moraine should read the descriptions in the connections in which they are presented.

JUNCTION OF THE DARIEN AND JOHNSTOWN MORAINES.

For nearly 7 miles northeast of the village of Richmond the Darien and Johnstown moraines are combined in a great interlobate deposit varying in width from 1½ to 3 miles. Beyond this the Kettle range bears the impress of a later stage, though it is probable the deposition of the constituent material was begun while the Darien and Johnstown moraines were being formed.

On the northwest side of this interlobate tract the slope rises abruptly from depressions in which lie No. 9, Whitewater, and Bass lakes to heights of 60 to 140 feet. This slope is the ice-contact face of the Johnstown moraine. There is generally a well-defined crest, broken by kettles, gravel knolls, and ridges. North of Holden Lake there is considerable subsequent filling behind the Darien moraine, but the morainal crest still stands 40 to 80 feet higher than the plain on the east. Southwest of Holden Lake, where there has been less filling, there is a relief of 80 to 120 feet. The crest on this side, which is also pitted with depressions, marks the Darien moraine.

In the town of Richmond the Johnstown crest is the higher of the two, but in the town of Whitewater this crest lowers somewhat and the Darien crest gains the ascendancy. From the latter a flat tract resembling an outwash apron declines gently westward to about the level of the western crest but does not cross it. In Richmond Township the filling between the crests is less uniform, being broken by sags and swells and some larger depressions, so that it resembles a continuous morainal deposit rather than an outwash from the other side. Cutting across this interlobate tract between Whitewater and Holden lakes is an eroded channel 20 feet or more in depth which was probably developed as an outlet for the glacial waters after the withdrawal of the ice. The fact that the inner face of each member of this belt is clearly and, for the most part, even abruptly defined, and that there is no indication that outwash from either moraine was carried across to the inner side of the other moraine, shows conclusively that as far north as sec. 24, T. 4 N., R. 15 E. (Whitewater Township) the ice fronts were contemporaneous in the occupancy of their respective outer terminal moraines. There is here no indication of difference in the vigor of the glaciers though before withdrawing from this interlobate tract the south front of the Delavan lobe appears to have melted back from the Genoa moraine.

Along the trough between the contiguous frontal slopes of the two glaciers much water doubtless collected and set up a vigorous flow toward the point where the ice fronts diverged. A large part of the interlobate morainal drift was assorted by this drainage, and much of the finer material was carried on and commingled with that washed directly from the ice fronts of the Darien and Johnstown moraines.

In this interlobate tract there was much opportunity for pushing and crowding the drift into an intricate series of ridges and depressions, and there was also doubtless much burial of masses of ice whose subsequent melting left depressions in the deposit. Northeast of Bass Lake is an especially intricate topography of abrupt, winding, and branching gravel ridges and depressions in which many slopes rise at angles of 30° or more. Some of the reliefs between the crests of ridges and the bottoms of adjacent hollows are 60, 80, or even 100 feet.

The material seen at the numerous surface exposures is mostly well rounded and ranges in size from coarse sand to cobblestones 8 to 12 inches in diameter. At some places larger stones occur. The deposit is generally well coated with one to several feet of gravelly loamy clay.

Three wells in the lower part of this tract near Bass Lake were reported as reaching rock at depths of 45, 64, and 85 feet. The only other wells of this tract reported as reaching rock was that of A. L. Peterson in the NW. ¼ sec. 7, T. 3 N., R. 16 E. (Sugar Creek Township) and that of George Bray, near the middle of sec. 11, Richmond Township, which reached the Galena dolomite at depths of 255 and 236 feet, respectively. Frank Larkin's well, in sec. 2, Richmond Township, did not reach rock in 230 feet, the lower part being in hard blue clay. The material penetrated by the wells is principally sand and gravel, with some layers of blue clay. In some parts considerable limestone drift is present on the surface. Crystalline bowlders are generally present on the surface but are not abundant.

A comparison of the percentages of the constituent materials of the gravels, as determined by estimates made at several points on both the Darien and Johnstown sides of the interlobate tract, shows that the drift in each of the constituent moraines retained much of its distinctive character and that at the same time considerable mixing took place within the tract. The most notable features of these estimates are the relative percentages of Niagara dolomite, which was principally of eastern derivation. From sec. 36, Whitewater Township, to sec. 10, Richmond Township (west of Turtle Lake), the Niagara material in the east side of the tract ranges from 63 to 74 per cent; in secs. 15 and 16, Richmond Township, the percentage ranges from 30 to 48. On the west side, the percentages of Niagara pebbles determined in secs. 25 and 35, Whitewater Township, and sec. 3, Richmond Township, were 28, 55, and 35, respectively. These percentages are rather high for normal drift of the Green Bay Glacier and indicate considerable mixing of the drift of the two glaciers, as would be expected in such an interlobate deposit. This is emphasized by the fact that just south of Lake No. 9, where the interlobate angle begins to open out and the Johnstown moraine becomes clearly distinct, the Niagara constituent drops down to 2 per cent and that nowhere to the west in this moraine does it rise to more than 13 per cent.

EXTRAMORAINAL CONDITIONS.

OUTWASH DEPOSITS.

DEPOSITS BORDERING THE DARIEN AND JOHNSTOWN MORAINES.

Character and amount.—While the Delavan and Green Bay ice fronts occupied the outer terminal moraines extensive bordering deposits of stratified drift were made by the waters escaping from the melting ice fronts. The relations of these deposits to the preglacial Rock and Troy valleys will be seen by referring to Plate II (in pocket). The material was probably deposited by many meandering streams rather than by a continuous overwhelming flood, but the extent and character of the deposits of sand and gravel show that the discharge of glacial waters was large in volume and vigorous in flow. Later, when the aggradation of the plains was about finished, the waters meandered sluggishly and spread over the whole a coating of loamy clay, varying in thickness from a few inches to 15 or 20 feet, so that few more fertile tracts are to be found in the region.

The amount of filling in the preglacial valleys is very considerable. At the front of the moraine in Harmony Township, where the elevation of the plain is 900 feet above the sea, there can be little less than 400 feet of filling. Three or four miles south of the moraine (sec. 5, T. 2 N., R. 13 E.) the well at the gravel-sorting plant of the Knickerbocker Ice Co., which is in a ravine about 30 feet deep, penetrated 300 feet of gravel and sand before reaching the rock bottom of the ancient valley. This well is fully a mile east of the axis of the valley, so that 330 feet is probably not the full thickness of the drift filling. A large part of this filling (see pp. 187–188) may be older drift that has survived the reexcavation of the valleys during the interval following the melting of the Illinoian ice sheet, and a large part of the balance may have been deposited by the waters flowing out from the early Wisconsin ice sheets. These possibilities should be borne in mind, although the part to be referred to each stage has not been distinguished in any of the exposures nor in available records of wells.

The terrace which forms the surface of this deposit declines gently to the south, and at the State line, 16 miles away, has lowered 100 to 120 feet. Here there is probably 300 feet of filling east of Beloit. The eastern tributary of the preglacial Rock Valley in southern Harmony and Johnstown townships shallows rapidly to the east, so that over the divide southeast of the village of Johnstown Center there is but 35 or 40 feet of gravel. Besides the present valleys of Rock River and Turtle

Creek this plain is trenched to some extent by tributary ravines, but for the most part it is nearly as flat as a floor.

From the vicinity of Richmond to a point about 4 miles southeast of the village of Darien such waters from the Delavan lobe as did not cross the divide to the west found their way through the older drift area by the valley in southern Bradford Township now traversed by Turtle Creek. That the flow through this valley was vigorous is shown by the extensive deposit of coarse gravel leading into it, and by a like deposit extending from the foot of the rock gorge to Rock River. That a considerable part of the gravel between this rock gorge and the State line was really washed through this valley is shown by the fact that the surface of the deposit declines westward from the foot of the gorge; that the gravels are considerably coarser where this eastern contribution comes in, and thence to the southward, than north of the junction; and that most of the exposures, especially in the eastern part of the deposit, show higher percentages of Niagara dolomite than those north of the junction.

Between the Darien moraine and the Turtle Creek rock gorge in southern Bradford Township very extensive erosion of these gravels took place after the withdrawal of the Delavan ice front from the moraine. An extensive lower plain was then developed by the removal of 20 to 30 feet of gravel; and in this lower terrace still later was cut a channel about 20 feet deep and one-quarter mile wide, whose bottom forms the present flood plain of Turtle Creek. A channel cut in the upper terrace joins the Turtle Valley from the north in northwestern Darien Township. Only the highest terrace in the area west of Darien is to be correlated with the formation of the Darien moraine.

The outwash plain bordering this moraine in Walworth Township is 1,000 feet above sea level at the front of the moraine. If the projection of Troy Valley is correct, and there is little ground for doubt that it is, there must be here at least 500 feet of filling outside of the moraine. Much of this filling, however, is probably older drift. This plain declines southward, connecting with the terrace along Kishwaukee River in Illinois.

West of the preglacial Yahara Valley, where Rock River now flows, the glacial front lay along the preglacial Brooklyn Valley to its head in T. 5 N., R. 9 E. (Oregon Township), crossing the Brooklyn moraine in the northwest part of T. 4 N., R. 10 E. (Union Township), 2 to 3 miles northwest of Evansville. Gravels were washed out from the moraine as far west as a mile east of Evansville and were swept southeastward along the valley to Rock Valley, forming the gently sloping plain traversed by the Chicago & Northwestern Railway west of the river. From the railway south to the slope of the upland the plain is largely marshy. At present it is drained eastward by Marsh Creek.

Most of the wells on this part of the outwash plain are shallow and do not penetrate the full thickness of filling, which is great, probably reaching nearly 300 feet near Rock River. According to E. Hindes, driller, the well at the county farm in the NW. ¼ sec. 13, Janesville Township, penetrated 223 feet of gravel and 30 feet of blue clay and gravel before reaching the rock bottom of the ancient valley at an elevation of 637 feet, and this was some distance south of the probable line of greatest depth.

Of 140 wells on these outwash plains concerning which information was obtained, 114 were reported as penetrating only sand and gravel below the superficial coating of clay.

The following logs show the character of the drift filling at several places in the Rock River valley:

Partial log of the fair grounds well, on the outwash plain in the northeast part of Janesville, Wis.[1]

	Feet.
Gravel	1 to 100
"Running gravel"	100 to 240
Calcareous arenaceous clay	215 to 240
Sand and gravel of drift origin; several kinds of rock represented	240
Sand, gravel, and calcareous clay	259
Sand and gravel, largely quartz and chert, a little granite, diorite, and some limestone	260 to 350

The elevation of the curb being 874 feet, the red shale of the Cambrian, which underlies the drift, was reached at an elevation of 524 feet above sea level.

The city artesian well drilled on the bank of the river, which has cut down about 100

[1] Geology of Wisconsin, vol. 2, p. 205, 1877.

feet in the valley filling, penetrated the following drift, as shown by the record at the office of the Janesville Water Co.:

Partial log of the city well at Janesville, Wis.

	Feet.
Coarse sand and gravel	145
Sand and gravel with clay in lumps	35
Red calcareous clay	15
Quicksand	46
Total drift	241

This well reached red shale of the Cambrian at approximately 520 feet above sea level.

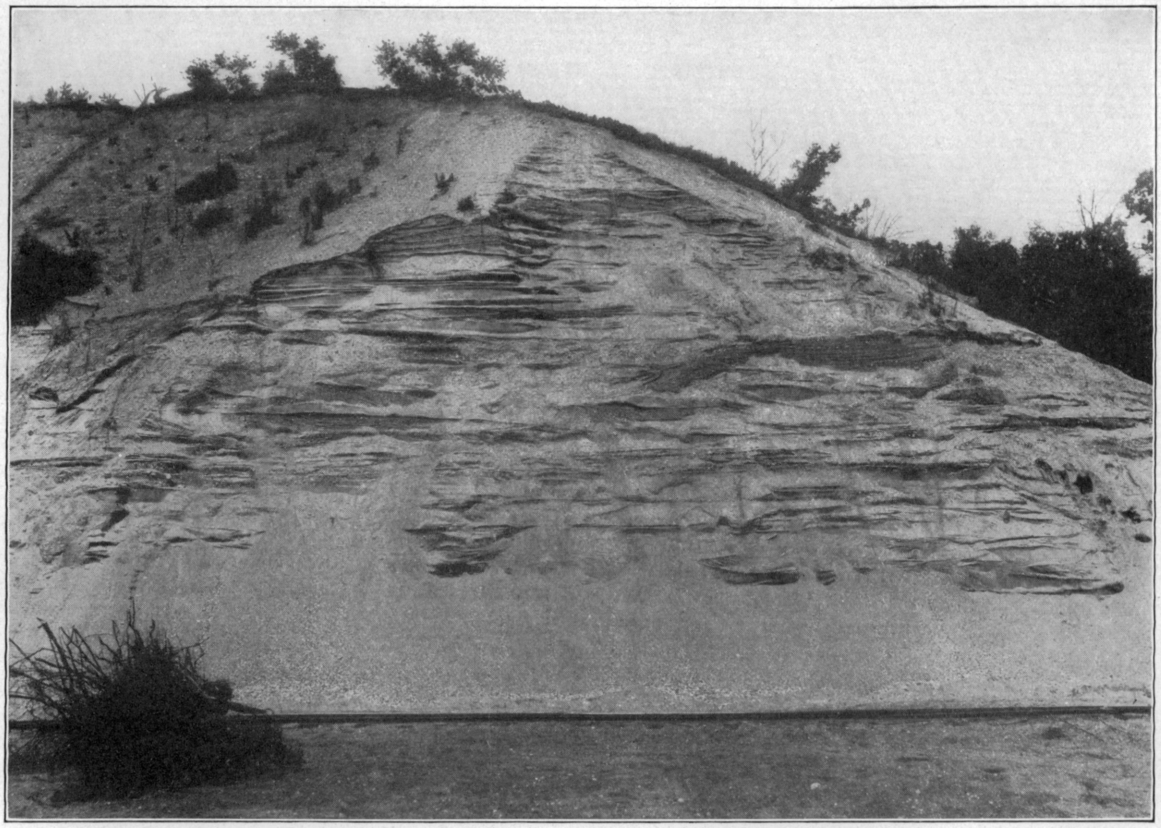
The well at the Knickerbocker Ice Co.'s gravel-sorting plant near the Chicago, Milwaukee & St. Paul Railway, 2 miles east of Janesville, sec. 5, La Prairie Township, is reported by E. Hindes, driller, to have penetrated sand and gravel to a depth of 300 feet before reaching the Cambrian sandstone at the bottom of the ancient valley. This well is in a small valley cut in the outwash. Excavation at this place exposes 30 feet or so of clean stratified gravels above the level of the curb. The bottom of the filled valley here has about the same elevation as that reached by the city wells 2 miles northwest, the deepest part of the valley probably being between these two places.

A well at Riverside farm, 3 miles southwest of Janesville, near the river, reached the Lower Magnesian limestone of the lower side slope of the buried valley beneath about 190 feet of gravel, as reported by E. Hindes; and C. H. Hayner's well penetrated sand and clay, mixed and in layers, over loose sand to a depth of about 218 feet before reaching the Lower Magnesian limestone bottom of a tributary buried valley a mile farther west. One of the layers of clay penetrated by M. A. Hayner's well near by was said to be 30 feet thick. No data from the wells show how much of this valley filling is to be referred to the last stage of glaciation, unless the occurrence of the clay layers penetrated by the above wells and others may be regarded as indicative of a different stage of sedimentation.

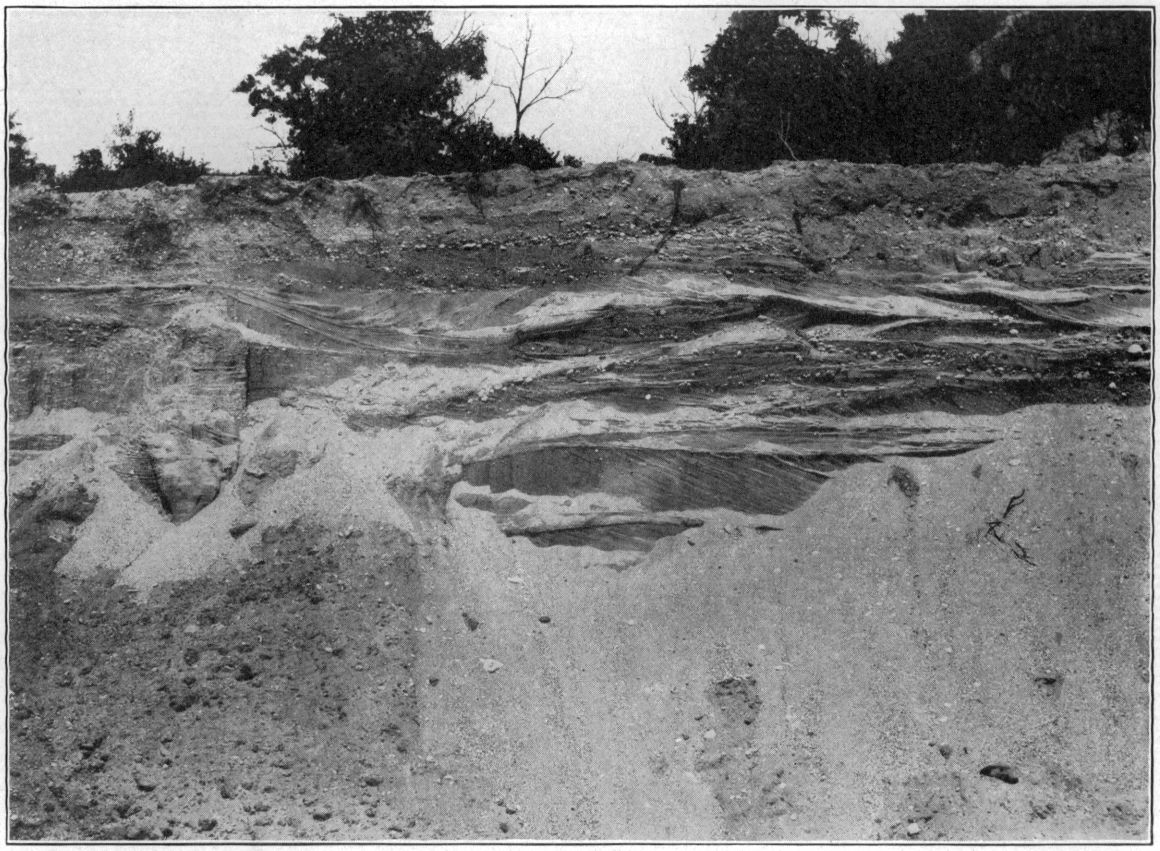
Numerous other wells penetrated beds of clay or "hardpan" in the lower part of the section. Till or "hardpan" occurring below the sand and gravel is probably to be referred to an earlier stage of glaciation, but where little else than sand and gravel occurs there is no means of determining how much of the filling was deposited in connection with the later Wisconsin glaciation and how much belongs to an earlier stage.

The coarser gravels of this deposit are exposed at numerous places in the slopes of Turtle Creek valley and on the line of the Chicago, Milwaukee & St. Paul Railway in the towns of Bradford and La Prairie, one good exposure being at the gravel-sorting plant of the Knockerbocker Ice Co. near the railway about 2 miles east of Janesville. Excavation in the bluff near the river in the southeastern part of Janesville affords an exposure of the finer material, the sand and gravel being beautifully stratified and cross-bedded as the result of the shifting currents of the glacial waters (Pl. XXIV, *A* and *B*); within 3 miles of the Johnstown moraine a large part of the pebbles reach 4 inches in diameter and not a few 8 to 10 inches. Some stones of this size are seen 7 miles from the moraine. Throughout La Prairie and Rock townships the great bulk of the material is coarse sand and gravel less than 2 inches in diameter. From southwestern La Prairie Township, where the outwash comes in from the east, south to the State line there is more coarse material as a consequence of the increased volume of water. With the finer material there is very much gravel ranging from 4 to 10 inches in diameter.

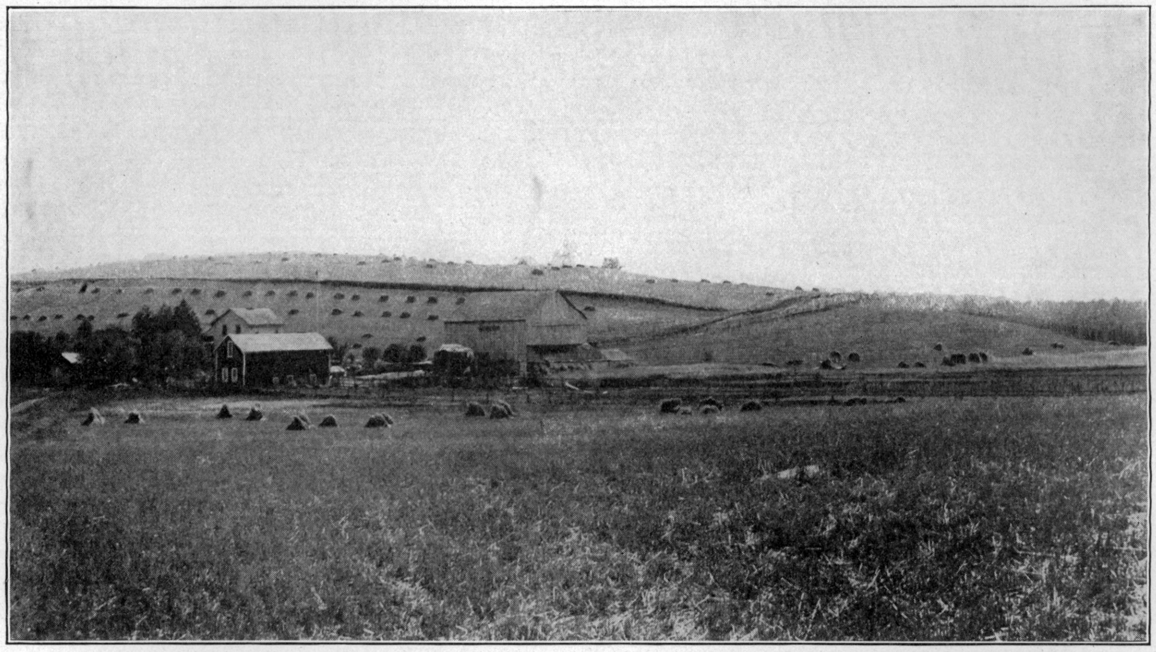
Between the Genoa and Darien moraines in the towns of Wheatland, Bloomfield, and Linn extensive nearly flat areas, declining gradually to the valley of Nippersink Creek, are in part underlain by gravel which was washed out from the ice front when it stood at the Darien moraine or was deposited as the ice front was melted back from the Genoa moraine. These gravels are exposed in many road cuts and other excavations beneath a superficial coating of clay. Much of this tract also appears to be occupied by ground-moraine deposits of till. These clay-coated gravels and nearly flat till areas so intermingle that their limits have not been determined with sufficient accuracy to warrant differentiation on the map, so that nearly the whole tract is mapped as ground moraine. The greater part of the glacial waters flowing from the south front of the Delavan lobe as it occupied the Darien moraine found an outlet to the south through the Genoa moraine at Genoa Junction, by the broad-bottomed valley now traversed by Nippersink Creek, which was probably excavated by these



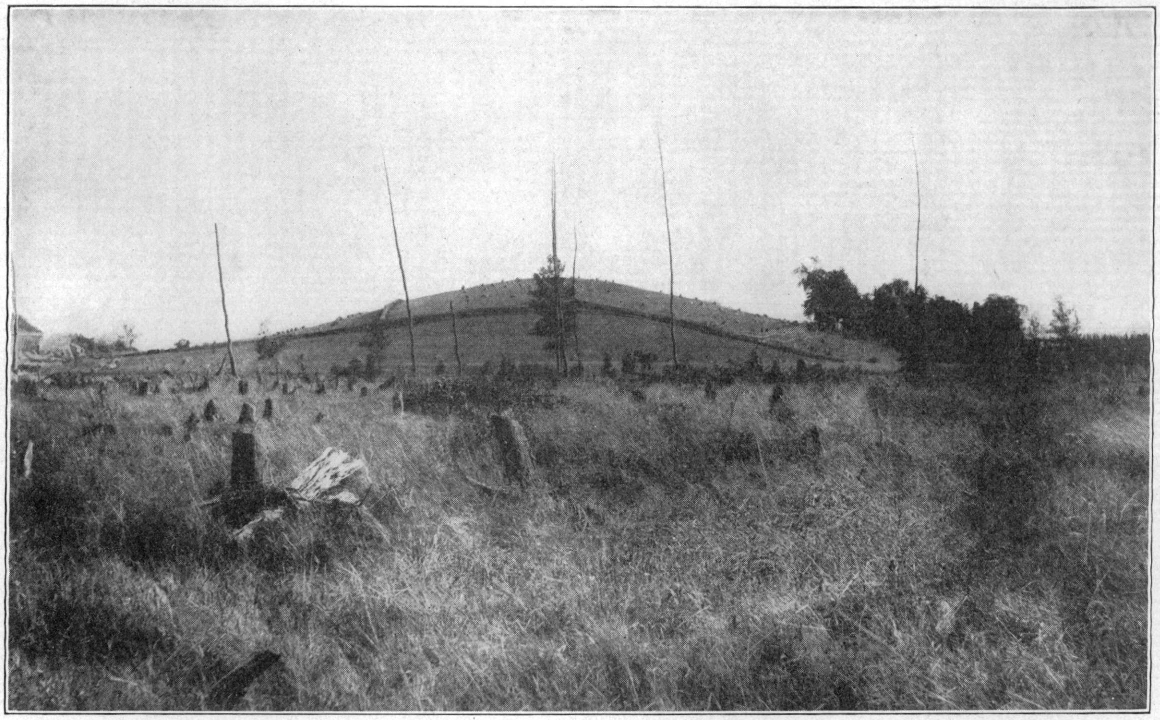
A. STRATIFIED SAND AND GRAVEL (OUTWASH DEPOSITS) FROM THE GREEN BAY GLACIER IN THE SOUTHEASTERN PART OF JANESVILLE, WIS.



B. DETAILS OF SAME DEPOSIT.



A. DRUMLIN 2 MILES WEST OF SULLIVAN, WIS.
View from the northeast.



B. TRANSVERSE PROFILE OF SAME DRUMLIN.
View from the north.

glacial waters. From the time of the abandonment of the Genoa moraine until the ice had almost entirely disappeared from Walworth County this outlet, which may be conveniently referred to as the Nippersink outlet, was an important factor in the development of this area.

Lithologic composition.—Analyses of the lithologic composition of the outwash gravels at 42 different exposures give some interesting results.

The foreign constituent of the gravels examined was nowhere greater than 29 per cent and averaged about 13 per cent.

In the part of the outwash deposit north of the southern parts of La Prairie and Rock townships the high percentages of Trenton limestone as compared with those of the Galena contrast with the results obtained in the Johnstown moraine. Doubtless this preponderance of Trenton material is largely due to the coming in of the outwash from west of Rock River. Allowance must also be made, here as elsewhere, for inability to distinguish well-worn pebbles of the Galena from those of the Trenton limestone by their lithologic character alone. The percentage of Niagara dolomite, though somewhat higher than in the Johnstown moraine west of Richmond, is nowhere more than 17 per cent. This seems to indicate that though a certain amount of the gravels from the Darien moraine may have crossed to the west of the rock divide in southeastern Johnstown, they mixed very little with gravels from the Green Bay Glacier in this part of the area.

The percentage of Niagara dolomite in the gravel terrace bordering the Darien moraine is somewhat lower than in the moraine itself. This would result from the southward flow of waters from the Richmond interlobate angle to the Turtle outlet, which would mix gravels from the Green Bay lobe with those from the Delavan lobe.

In that part of the deposit extending from southwestern Bradford, southern La Prairie, and southeastern Rock townships to the State line, the percentages of Trenton and Galena material show that the contribution from Green Bay Glacier was still very large though no longer predominant. The increased percentages of Niagara dolomite at most of the exposures show clearly the incoming of gravels from the Delavan lobe through the Turtle Valley. The lowest percentages of Niagara were found in the western part of the deposit, as though the waters from the Green Bay Glacier had been largely crowded to that side by the outflow.

SUGAR RIVER BASIN.

In Union Township, where the Brooklyn moraine lies across the ancient Brooklyn Valley, it is bordered on the south by a flat gently sloping plain locally known as Jug Prairie. Wells on this plain are driven through the clay soil and 18 to 40 feet into loose gravel. Gravels are also slightly exposed in road cuts, so that the plain is evidently of outwash. The gentle slope, however, rises directly northward to the front of the Brooklyn moraine, and it may be that the outwash was from this moraine and antedated that from the Johnstown moraine. The narrow valley of Allen Creek, which formed the outlet for the basin north of the Brooklyn moraine, cuts through both moraine and outwash terrace in secs. 16 and 17, so that from this point southward to Evansville it is not clear what part of the gravels are to be referred to the Brooklyn moraine and what to the later glacier. South of Evansville Allen Creek valley broadens to a width of 1 mile and is occupied by a marsh with an abrupt eroded bank on the east. West of the creek the village of Evansville stands on a flat plain which extends thence a mile or more south and southwest across a preglacial valley to a rock ridge near the town line. This plain resembles an outwash terrace, and wells in it penetrate gravel below a clay soil, but it is not clear how it could once have been part of the outwash plain bordering the moraine east of the creek and have been subsequently cut off by such a broad, shallow, marshy valley. Like Jug Prairie it may be a remnant of earlier outwash associated with the formation of the Brooklyn moraine. The position of the Brooklyn moraine, and the narrow outlet for the basin shut in north of this moraine, concentrated the flow from a frontage of 7¾ miles of the Green Bay Glacier along this valley in addition to the direct flow from the 2-mile frontage south of the Brooklyn moraine. The resulting stream escaped westward to Sugar River along the course of the present Allen Creek, and its flow may have been sufficiently vigorous to keep the valley open. It seems impossible to say whether or not the gravels west of the creek belong to the later Wisconsin substage. The col in the rock ridge at Arthur Spencer's quarry, 2 miles southwest of Evansville, now traversed by a little creek, may have served as a spillway for the flooded main stream, and the overflow through it may have deposited the gravels in question. The sandy outwash plain extends into the narrow head of the east-west part of Allen Creek valley, but for 3 miles in that part (which is only one-fourth of a mile in width) no similar deposits are seen. The flat bottom extending from the foot of the abrupt high slope on the north to the low sandstone hills on the south is marshy. In secs. 11 and 14, T. 3 N., R. 9 E. (Albany Township), however, where the valley broadens, the present stream begins to cut into a flat gravel terrace which extends thence west to Sugar River. A shallow marshy depression heading in the col between the Lower Magnesian limestone hills in sec. 14 and extending thence southward 6 miles to a junction with the channel of Sugar River in sec. 14, T. 2 N., R. 9 E. (Decatur Township), 2 miles above Brodhead, suggests that the glacial waters entering the valley from the east were diverted southward along the east side of the valley by the vigorous southward flow along the Sugar Valley.

In the adjacent parts of Oregon, Brooklyn, and Union townships the basin shut in between the Johnstown and Brooklyn moraines is occupied by a flat plain sloping gently from the morainal front. Wells penetrate gravels beneath the clay soil to depths of 30 to 40 feet or more. This plain is pitted in places with sags, some of which contain ponds. The basin drained southeastward through the narrow cut in the Brooklyn moraine now traversed by the railroad.

It is not apparent how much of the outwash material beyond the rock ridge in the valley tributary to Sugar River came from the Johnstown moraine and how much from the Brooklyn moraine, though a small terrace back of the Brooklyn drains through breaks in this moraine. The outwash plain declines southward and within a very short distance passes below the level of the marsh which extends thence to the main valley east of Dayton. It is the writer's opinion that only a comparatively small part of the valley filling here is referable to the later Wisconsin substage.

No outwash is found on the slopes or the crest of the rock ridge near the Montrose town line, which, outside the moraine, is barely covered with scattered drift and loamy clay soil. In the next valley, where the bulky moraine is cut through by the Illinois Central Railroad, and in two small valleys in sec. 36, T. 6 N., R. 8 E. (Verona Township), where the relief of the moraine is particularly strong, such outwash as was carried from the ice front was mostly washed through the narrow tributary valleys to the main valley of Sugar River between Paoli and Basco. In the main valley the outwash terrace is well developed, but it seems improbable that all its material could have come through the valleys heading at the moraine; yet no other source is apparent. Thence northwest to Badger Creek valley at Verona no outwash borders the moraine on the rock ridge and slopes, which carry only a scattering of older drift beneath the loamy clay soil outside the moraine.

Outside the moraine near Verona the valley of Badger Creek has a broad alluvial flat in which no exposures showing the character of the material underlying the black alluvial soil were noted. One mile southwest of the moraine front the flat merges with the still broader plain of the Sugar River valley. Not until the stream reaches the south line of the town does it begin to cut below the level of the plain. From this line southward it is bordered by a flood plain a few rods to one-half mile in width cut in the broader plain, which extends from side to side in the preglacial valley, a width of 1 to 2 miles. Near Belleville, in the south part of Montrose Township, the alluvial plain lies 10 to 15 feet below the broad terrace, in which at least one well is reported to have penetrated 100 feet or more of sand and gravel without reaching rock.

Two miles northwest of Belleville the outwash fills the outlet of a tributary valley and is cut through by the stream.

In the 5 miles from Paoli to Belleville the outwash terrace lowers from 905 to 868 feet above sea level, a fall of 7⅖ feet per mile. Between Belleville and Dayton the flood plain broadens, and the outwash-terrace remnants are correspondingly narrowed. In this 3 miles the slope is about 4 feet per mile. At Dayton and midway between Dayton and Attica the ancient valley is constricted by ridges of

Lower Magnesian limestone. Between these two points the outwash terrace is confined to the east side of the stream, where it spreads out as a broad sandy deposit, filling the outlet of the valley tributary on the north, producing the extensive marsh beneath which the outwash deposits in southwestern Oregon Township disappear and crowding the outflowing streamlet to the south side against the limestone ridge. Two miles north of Attica the valley again broadens and is occupied by a sandy plain, at the west side of which the stream meanders through a narrow flood plain cut 20 feet below the main flat. Opposite Attica the elevation of this plain is 838 feet, a decline of 3 feet per mile in the 6 miles between Dayton and Attica. A well at Attica close to the west side of the ancient valley is said to have penetrated 100 feet of sand without reaching rock, and another in a similar position 1½ miles southeast reached sandstone beneath 125 feet of loose sand.

In Albany Township the outwash terrace extends across the mouth of the Little Sugar Valley, which here comes in from the west, standing 20 feet above the broad alluvial bordering flat. The relation here shows that the outwash came from the north and perhaps partly from the east and must have ponded the waters of this stream westward to Monticello, a distance of 8 miles. The alluvial or lacustrine flat thus formed in the Little Sugar Valley is about a mile in width and is still somewhat marshy.

In the broad valley east of Albany, beyond the hills of Lower Magnesian limestone which obstruct the valley south of the Allen Creek fault line, is found the continuation of the outwash plain. Just north of the rock ridge east of the river at Albany the surface of the plain is a little higher and is marked by sandy undulations, apparently dunes.

It is not evident whether Sugar River was diverted from the main valley east of the rock ridge at Albany to the narrow gorge west of the ridge as a consequence of filling of the former by outwash from the last glacier or whether the diversion occurred earlier. A gravel terrace, apparently a part of the main valley plain, occupies the gorge except in its narrowest part; but the wider part may not be due to erosion by the river, for the ridge on the east is one of the resurrected hills of Lower Magnesian limestone from which the coating of sandstone has been largely stripped, and the sandstone on the west may have been readily removed by a minor tributary or even by surface wash. If this gorge was eroded previously, the incoming of the glacial waters from the east may have crowded the current to the west side of the valley and caused it to find exit through the sag (washing gravels through when the filling reached a sufficient height) and have left it there, incising its channel when the glacial flood subsided. This gorge can not thus be taken as evidence in itself that the Sugar River valley was filled prior to the later Wisconsin substage and was not reexcavated. However, the relations of the Brooklyn moraine to the head of the tributary valley in southwestern Oregon Township and the discharge by the way of Allen Creek makes a filling at the early Wisconsin substage not improbable, and the restraining influence of the rock barriers in the course of the river in the region of Rockford, Ill., would be felt in this valley as well as in the preglacial Rock River valley to which it is tributary, preventing any great amount of reexcavation after the early Wisconsin substage of glaciation.

Between Albany and Brodhead the broad preglacial valley of Sugar River is obstructed in part by hills of Lower Magnesian limestone from whose uneven surface most of the overlying sandstone has been eroded. It is also obstructed in part by deposits of earlier till which were not removed by post-Illinoian erosion. From Brodhead southward the sandy valley plain descends about 6 feet per mile, and in Avon Township (T. 1 N., R. 10 E.) it reaches the level of the flood plain and merges into a marsh 10 or more square miles in extent. North of the river, ditches along the road crossing this marsh expose 2 to 3 feet of peat overlying sand, and south of the stream is clayey loam overlying sand.

The evidence indicates (see p. 188) that the amount of reexcavation accomplished by Sugar River and its tributaries following the disappearance of the Illinoian ice sheet was comparatively small, and if the amount of refilling is to be divided between the drainage of the earlier and the later Wisconsin glaciers a very moderate amount can be referred to each. It seems probable, however, that at least the upper part of the valley filling is Wisconsin outwash drift and that some of it is from the last Green Bay Glacier. More than this can not now be determined.

Northwest of Verona, in adjacent parts of secs. 4, 5, 8, and 9, a flat terrace borders the abrupt marginal ridge of the moraine and is underlain by rock and thinly covered with gravels and scattered bowlders. A part of this may be older drift but very likely some of it, though not a great deal, is outwash. The glacial waters escaped southward by a narrow ravine bordering the front of the moraine. For 2½ miles northwestward, where the ice lay along the crest of the rock ridge and deposited morainal material in the heads of the ravines which cut the west slope, no gravel appears to have been washed down from the moraine front. This seems very strange, but in reality most of the waters may have escaped down the east slope of the rock ridge beneath the ice and found egress by way of the ravine which cuts the moraine 3 miles northwest of Verona (NE. ¼ sec. 5, T. 6 N., R. 8 E.).

In the west part of secs. 19 and 30, Middleton Township, where the drift blocks the head of a preglacial valley, the moraine was bordered by a small temporary lake. A peculiarity of this glacial lake was that it appears to have had a subterranean outlet to the valley west of the ridge through the St. Peter sandstone which underlies the limestone cap; at least no evidence of a surficial outlet channel was noted, and there is in the lower northeast slope of the basin a sink hole such as is usually only found overlying limestone formations. The bottom of the basin below the level of this sink is somewhat silted up, and some pebbles and bowlders, probably ice transported, lie on the lower west slope. Bordering the moraine front the narrow flat terrace on which the road is situated represents the small amount of direct outwash from the ice front.

On the rock ridge to the north no marginal deposits occur except a little filling in the head of a blocked ravine in the SE. ¼ sec. 13, T. 7 N., R. 7 E. (Cross Plains Township).

WISCONSIN RIVER BASIN.

Although it seems probable (see pp. 191–193) that the greater part of the glacio-fluviatile material in the Wisconsin and tributary valleys was deposited in the valleys prior to the incursion of the later Wisconsin glacier, the writer is loath to believe that there was no outwash from the last Green Bay Glacier. From about 900 feet above sea level at the moraine front near Cross Plains a gravel terrace extends down the Black Earth Valley for 3 or 4 miles to a point where, at 825 to 830 feet above sea level, it appears to merge with a less rapidly declining terrace which in turn is continuous with the upper terrace at Mazomanie. The relations are thought to indicate that waters from the later Wisconsin ice front at Cross Plains deposited gravels as far down the valley as the southwestern part of T. 8 N., R. 7 E. (Berry Township), building them up to grade. Beyond this point the water cut into the earlier upper terrace and developed a second terrace. At Black Earth village the second terrace lies about 8 feet below the upper; at Mazomanie it lies 15 to 20 feet below and has a width of five-eighths mile, including the narrow inner valley of Black Earth Creek. The main part of the village is built on the lower terrace, which extends on down the valley for 4 to 5 miles. To the point where it is cut by Blue Mound Creek in the eastern part of T. 8 N., R. 5 E. (Arena Township) it is bordered on the north by a remnant of the higher terrace. Beyond this it merges with the broad sand flat which spreads out as the main bottom of the Wisconsin Valley. Evidently at the later Wisconsin substage this latter broad terrace was the flood plain of Wisconsin River, to whose level the waters discharging down Black Earth Valley graded the second terrace.

Four valleys are tributary to Wisconsin Valley at and north of Mazomanie. Of these Black Earth Valley is the southernmost. The mouth of the third valley from the north is dammed by the upper (earlier) terrace sands and gravels east of Mazomanie. In this valley the limit of glaciation is near the schoolhouse in the NE. ¼ sec. 20, Berry Township. A little sand and gravel are seen near the limit of the till sheet, and sand extends a fraction of a mile farther down the valley, west of which the valley bottom is a marshy flat, varying in width from one-eighth mile or less to one-half mile or more. Evidently the waters discharging into this valley from the front of the Green Bay Glacier were ponded by the obstructing upper terrace at its mouth until a channel was cut through the deposit to Black Earth Creek. This channel was deepened at a rate corresponding with the lowering of the second terrace by erosion at and below Mazomanie. After the disappearance of the ice from the head of the valley the deepening of the valley was continued by the small creek which now discharges through it. So little has this accomplished, however, that the valley bottom above is still marshy.

The second valley from the north, that of Halfway Prairie Creek, must have been an outlet for gravel-bearing waters at the earlier stage, as was the Black Earth Valley, for its broad flat bottom is graded up to the upper terrace west of its mouth. Some of the sand and gravel west of the limit of glaciation, which is near the west line of sec. 8, Berry Township, may have been deposited at the later Wisconsin substage, but most of it was probably deposited earlier. The erosion and the channel in and west of the valley mouth was doubtless begun at the same time as that of the third valley.

In valley No. 1 gravels are exposed in the creek bank within 100 rods of the limit of the Green Bay drift, which is in the SW. ¼ sec. 32, T. 9 N., R. 7 E. (Roxbury Township), but on the west they pass below the level of the marsh, which extends down the valley to the remnant of the upper terrace which obstructs the valley's mouth. These gravels are probably later Wisconsin outwash, deposited above the level of the obstructing dam. The upper terrace gravels in the Wisconsin Valley ponded the waters in valley No. 1 up to about 800 feet above the sea, and they were lowered only with the lowering of the water in the Wisconsin Valley and the erosion of a channel through the barrier.

The removal of the upper terrace sands and gravels from much of the northern part of Mazomanie Township was probably accomplished or at least begun during the later Wisconsin substage. Two partly lowered tracts stand as islands in the marsh south of the river.

From the point where Wisconsin River cuts through the terminal moraine, about a mile north of the village of Prairie du Sac, northward to the Baraboo quartzite range, the terminal moraine is bordered by an extensive terrace or outwash plain. The relations of this terrace to the moraine are such as to indicate that it was completed, at least, by the deposition of sand and gravel washed out by waters issuing from the Green Bay Glacier. A narrow remnant of a gravel terrace borders the moraine for 2 or 3 miles south of the bluff opposite the village of Prairie du Sac, and the relations indicate that it probably originally continued westward with the upper terrace west of the river. Much of the sand and gravel, however, has been removed from a triangular tract several square miles in extent with its apex at the river north of Prairie du Sac, so as to form a lower terrace. The relations of the terraces here and in the vicinity of Mazomanie (see pp. 191–192) indicate that most of the filling in the valley was of earlier deposition. With the extension of the later Wisconsin glacier the waters discharging therefrom probably deposited the uppermost sands and gravels near the morainal front, building the terrace up to grade. Farther down the valley the waters were eroding the earlier deposits and developing a second terrace. Possibly a slight recession of the ice front from the outer margin of the moraine led to a cessation of deposition on the terrace. The waters became concentrated by a sag where the river now cuts the moraine and extended the erosion of the terrace upstream to the front of the moraine. The second terrace, southwest of Prairie du Sac, is marked by a series of slight steps dropping eastward, the result of the gradual shifting of the current eastward as the valley was deepened. On this interpretation the deposition of the uppermost of the outwash material near the moraine front and the development of the second terrace in the towns of Prairie du Sac and Mazomanie are to be correlated with the later Wisconsin glaciation.

DEVILS LAKE.

While the ice front stood at the moraine blocking the Devils Lake Gorge at the east and north there was a considerable depression between the two opposing ice dams. The bottom of the rock gorge (see p. 111) probably has an elevation about 500 feet above sea level, or nearly 500 feet below the surface of the lake. A recent survey of the lake shows the water to have a maximum depth of 43 feet, so that beneath the lake bed there is more than 400 feet of filling. When the Wisconsin Valley to the south was silted up to a level about 800 feet above the sea it is probable that the filling extended through the gorge and into the basin on the north, so that when the ice fronts crowded into opposite ends of the gorge the depression between them may have been 150 or 160 feet deeper than now. Waters from the melting ice must have filled this depression between the ice walls until they overflowed at the lowest point of the rim, unless there was opportunity for back drainage beneath the ice. Salisbury and Atwood[1] state that the water is known to have risen at least 90 feet above the present level, for drift bowlders, believed to have been dropped from floating ice, have been found on the West Bluff at this height.

A. C. Trowbridge informed the writer that he found a crystalline bowlder within 25 feet of the level of the col above Messengers, near the East Sauk road west of the lake. This is about 200 feet above the present level of the lake. This bowlder must have been transported on floating ice from the front of the glacier at either the north or the east end of the gorge, and it indicates that the waters may have overflowed by way of this col and have discharged into the Baraboo basin by a ravine now tributary to Skillets Creek.

At Kirkland a terrace slopes gently from the moraine to the water's edge. This, with the part beneath the lake and at its north end, is the surface of the subaqueous filling washed into the flooded basin from the adjacent ice fronts. The occurrence of pits along the margin where this terrace at Kirkland lies against the talus of angular quartzite blocks suggests that there was either an outlet for the glacial waters through the loose talus beneath the drift or that subsequent settling and wash have carried the sand farther down into the interstices of the loose-lying talus deposit. That the lake does not now have an outlet at the surface, though constantly fed by spring waters, is doubtless due to the fact that its surplus waters find such subterranean outlet. That the whole basin is not thus drained is probably due to the finer and more compact character of the silt underlying the part of the basin now submerged.

Within the loop of the moraine on the south range east of Devils Lake the only evidence of the work of the glacial waters is found in lacustrine deposits which underlie the flat 1½ to 2 miles east of the lake. Three wells, reported to have penetrated drift to depths of 130, 151, and 201 feet, show that a valley cut in the range here has been partly filled by morainal and outwash drift. The material penetrated by one of these wells, that of W. Stopper, is said to be clay 9 feet and quicksand 142 feet. The lacustrine silt, sand, and gravel are exposed in cuts near the road corners on the west part of the flat and in eroded gullies. An interesting feature at the former place is the occurrence of distorted laminæ between undisturbed ones. The distorted laminæ are thrown in little overthrust folds all in the same direction. This may have resulted from the dragging of a floating mass of ice on a mud bank under the pressure of strong winds, or from the push of lake ice grounded on the mud bank due to expansion under recurring hard freezing. Continued deposition later covered the contorted layers with undisturbed laminæ.

[1] Wisconsin Geol. and Nat. Hist. Survey Bull. 5, p. 133, 1900.

GROUND MORAINE AND DRUMLINS.

DEPOSITION AND OBSCURATION.

It is probable that by far the larger part of the glacial drift was deposited as ground moraine—that is, as débris accumulated beneath the ice during its advance over the whole area traversed. Ground-moraine deposits, however, are in many places later covered to a greater or less extent by accumulations of drift formed at the margin of the glacier during the melting of the ice sheet, or during stages of halt or readvance which may interrupt the general deglaciation. Such deposits, though not necessarily greatly different from those formed during the advance, are more apt to be concentrated in ridges or belts and are to be distinguished from the ground moraine proper. Associated with these terminal-moraine belts there may be stratified deposits, consisting of drift washed from the moraines by waters from the melting ice front and laid down over more or less extensive tracts of ground moraine. Extensive marshes, formed over the lower parts of the ground moraine after the disappearance of the ice, still further limit the areas to be mapped as ground moraine. Thus it is that the part of the drift mapped (Pl. III, in pocket) as ground moraine, especially within the limits of the Lake Michigan Glacier, occupies somewhat limited and disconnected parts of the area. In places the boundaries between the ground-moraine tracts and the rather indefinite terminal-moraine belts are of necessity somewhat arbitrarily drawn.

LAKE MICHIGAN GLACIER.

North of the latitude of West Bend, in Sheboygan County, and in adjacent parts of Manitowoc, Washington, and Ozaukee counties, there are several tracts, with a total area of 80 square miles or so, between the west margin of the red till and the interlobate moraine where the ground-moraine deposits do not appear to have been greatly obscured or buried beneath drift deposits made during the recession of the ice front as the glacier melted. The topography over most of these tracts is a gently undulating plain with but moderate relief and no definite alignment of the undulations. East of Milwaukee River, in T. 13 N., R. 21 E (Sherman Township), and to some extent in Fredonia Township on the south, a well-marked drumlin topography with axes trending somewhat south of west has been developed. There are about 80 more or less distinct drumlins, some of them nearly perfect in their symmetry. They vary in length from 60 rods to three-quarters of a mile and in height from 30 to 100 feet. This drumlin topography is overlapped by the red-till moraine on the east. West of Milwaukee River is a high rolling area with bulky drift hills but without drumloidal form and trend. Drumlins are not developed within less than 6 miles of the limit of the advance of Lake Michigan marked by the interlobate moraine.

The drift of the ground moraine is moderately compact bluish-gray till of the ordinary type. The average thickness shown by the records of 28 wells and at two limestone outcrops is 113 feet. Several wells over 200 feet in depth do not reach limestone, so that it is probable that the thickness of the drift, which of course probably includes more or less of the earlier stages of glaciation, is somewhat greater than 113 feet. The log of John McLaughlin's well in one of the highest parts of the area, 2 miles northwest of Cascade, shows something of the character of the drift.

Log of John McLaughlin's well in the SE. ¼ sec. 13, T. 14 N., R. 20 E. (Mitchell Township).

	Feet.
Clay	25
"Hardpan"	50
Gravel	25
Sand	60–80
Yellow clay } Gravel }	49
	229

The yellow clay in the lower part suggests that an interval of exposure to oxidation may have followed its deposition and that it may represent an earlier stage of glaciation.

Another well 3 miles south of Cascade penetrated the following deposits:

Log of August Weinhold's well in the NW. ¼ sec. 9, T. 13 N., R. 21 E. (Sherman Township).

	Feet.
"Hardpan"	90
Clay	25
Sand	10
Clay	25
"Hardpan"	8
Drift, kind not reported	60
Niagara dolomite	22
	240

The only exposure of bluish till noted in the lake bluff north of the south line of Sheboygan Township is in the NE. ¼ sec. 34, T. 16 N., R. 23 E. (Mosel Township), where it apparently rises abruptly above the beach for a few rods. The till here is very stony, much more so than the overlying red till, and the accumulation of bowlders 1 to 3 feet in diameter on the beach from the erosion of this till has retarded wave action and caused the formation of a salient in the bluff face.

South of the latitude of West Bend in the eastern part of the belt bordering Lake Michigan the only part of the drift which is now considered as strictly ground moraine occupies narrow belts between the Lake Border terminal morainal ridges; and even here it is in places covered by marsh deposits. In these tracts, so far as can be determined from small exposures and from records of wells, the deposit is of till of the ordinary type.

In the tracts west of the Lake Border moraines and south of West Bend there is generally a very gently undulating topography. Parts of the towns of Brookfield, Pewaukee, Delafield, Waukesha, and Genesee are very hilly, and many of the hills have the forms and trend of drumlins. The general direction of the glacial advance, as shown by striæ, ranged from southwest to somewhat north of west. The arrangement of the drumlins is in accordance with this. Drumlin topography is much less markedly developed than in the area of the Green Bay Glacier. About 60 drumlins occur in this part of the area east of the interlobate moraine. Dolomite is exposed at the surface in the immediate vicinity of some of these hills, but no rock cores have been found by wells on or near them.

Here also the ground moraine consists of bluish clayey till of the ordinary type, with the usual amount of associated assorted material. At many places the drift is very thin and numerous exposures of the dolomite occur. In other places, as in adjacent parts of Polk and Jackson townships (T. 10 N., Rs. 19 and 20 E.), ancient valleys in the rock have been obliterated by thick deposits of drift. Two wells in sec. 6, Jackson Township, penetrated 300 and 367 feet of drift, of which nearly one-half probably belongs to an earlier deposition. An estimated average of the thickness of the drift throughout these ground-moraine tracts is 45 feet.

In the higher ridged parts of southern Waukesha County the drift of the ground-moraine is in general very stony, the bulk of the stony material being from the Niagara dolomite. The records of wells in this tract show considerable deposits of sand and gravel below the till. Some wells encounter "hardpan," possibly an older drift sheet. One well about 3 miles west of Mukwonago was drilled to a depth of 240 feet before it passed through the deposit of loose sand encountered below a moderate thickness of stony till. In drilling Alexander Smart's well near Saylesville, beneath 80 to 90 feet of material, at least half of which was sand, a deposit of fine, sticky, blue, gritless clay 80 to 90 feet in thickness was encountered.

In the lower ground-moraine tract of the towns of Muskego, Norway, Dover, and Brighton (Tps. 2 to 5, R. 20 E.), the till is more clayey, containing less coarse material and less sand. At some places thicknesses of 100 feet showed very little sand or gravel. The bulk of the pebbles here are from the Niagara dolomite, but one or two exposures showed a considerable ingredient of bluish shaly rock resembling the Devonian beds at Milwaukee.

From some places in the Walworth County tract, thicknesses of 100 to 180 feet of solid bluish till, with but little sand, are reported. One well 3 miles southwest of the village of Honey Creek penetrated 100 feet of solid clay till, underlain by 137 feet of sand. There is great variability in the drift, some wells being almost entirely in sand and gravel. The deposits in these tracts vary from nothing to 328 feet or more in thickness, the average probably being between 100 and 150 feet.

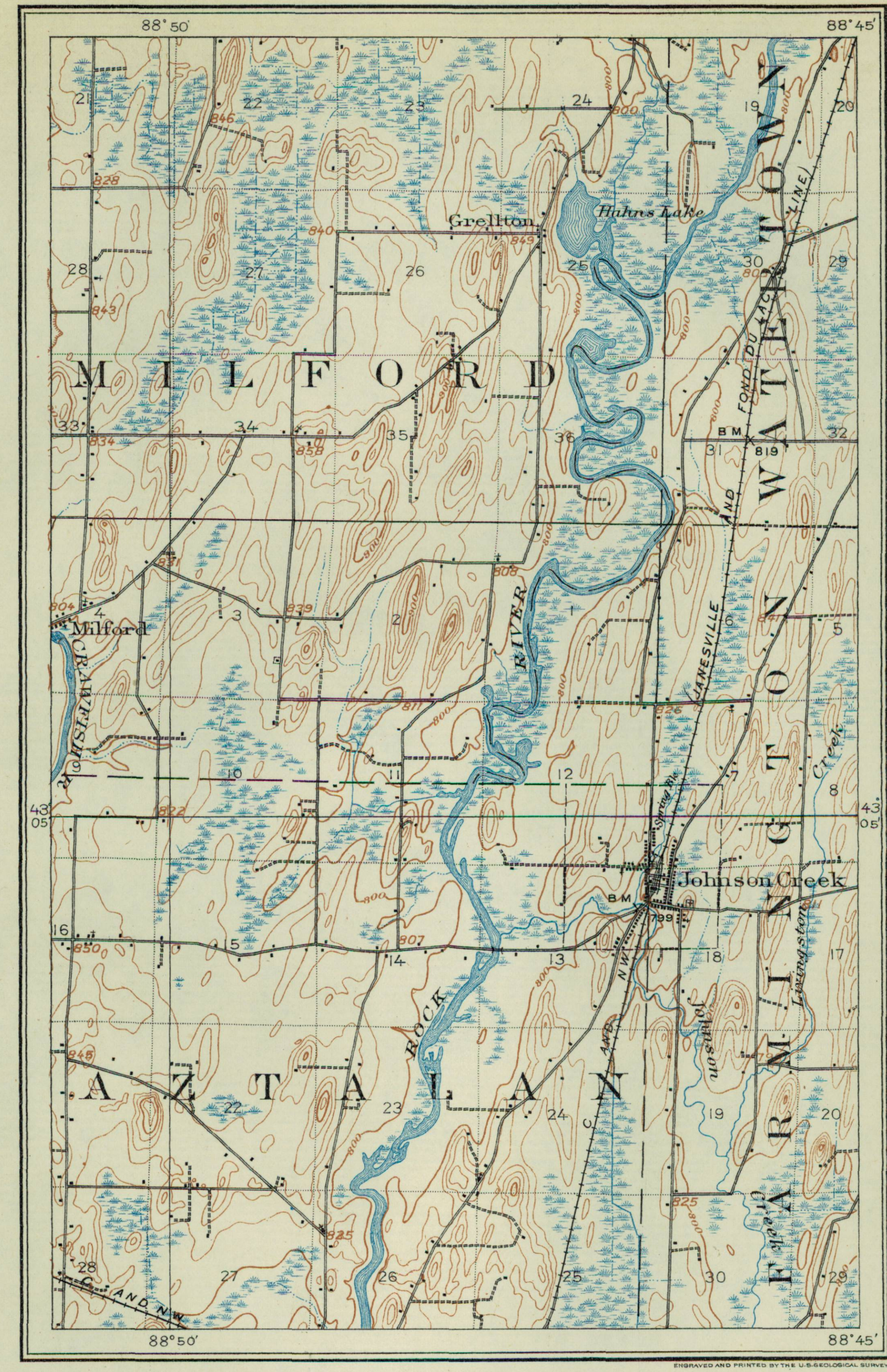
An estimate of the lithologic composition of the drift exposed at the surface, based on the sorting of pebbles at five places in Waukesha and Washington counties, gives about 89 per cent local material, of which fully 87 per cent is Niagara dolomite. There is a small contribution from the Milwaukee and Waubakee formations, some sandstone and chert, and, rarely, a few quartzite pebbles. About 11 per cent is foreign crystalline rock.

GROUND MORAINE OF THE GREEN BAY GLACIER.

Topography.—In the western half of Fond du Lac County and adjacent parts of Green Lake and Dodge counties the ground moraine of the Green Bay Glacier forms a gently undulating plain which is devoid of distinct topographic features and which, over the Trenton and Galena formations, is for the most part nearly flat. Where any considerable thickness of St. Peter sandstone occurs beneath the margin of the Trenton limestone there is something of an escarpment, not greatly obscured by the drift, and the surface drops to a lower level on the Lower Magnesian limestone, from which it rises westward with the rising rock surface or drops to valleys excavated in the Cambrian sandstone. Where the St. Peter sandstone is thin or absent the plain is continuous from the Trenton out over the Lower Magnesian tracts. Both the surface and the margin of the lower limestone are more irregular than those of the Trenton, and hilly tracts result from the thin mantling of the eroded rock surface with drift.

In Marquette County and northwestern Columbia County, where the drift is underlain by the Cambrian sandstone, extensive marshes are interspersed with sandy tracts, in parts hilly. In places limestone-capped remnants rise above the general plain, as do many sandstone hills from which the limestone has been removed and which are thinly mantled with drift. Most of these hills have no special form or orientation, being principally hills of rock rather than drift. Scattered among them, however, are occasional elliptical hills whose forms and orientation are evidently due to glacial action.

Southwest and south of Fox and Beaver Dam lakes and eastward through the southern half of Dodge County, extending up over the Niagara escarpment and spreading thence over the upland to the east and northeastward into Fond du Lac County, there is a remarkable belt of drumlin topography. Primarily it is



DRUMLIN TOPOGRAPHY IN CENTRAL PART OF JEFFERSON COUNTY, WIS.

Scale $\frac{1}{62{,}500}$

1 ½ 0 1 2 Miles

Contour interval 20 feet.

Datum is mean sea level.

1917 House Doc. No. ; 64th Cong., 2d Sess.

drift topography, a specialization of the ground moraine, and appears to be little influenced by the configuration of the underlying rock surface. It consists of elongated ridges and elliptical hills of glacial drift with their longer axes arranged parallel to the direction of the ice movement.[1] Adjacent ridges seem to lie parallel or to diverge but slightly, but when considered as a whole, they are seen to radiate widely in the direction followed by the spreading currents of the deploying glacier. (See Pl. III, in pocket.)

Interspersed with the drumlins and drumloidal ridges are hills of less definite or even of very indefinite form, simple drift undulations, but the prevailing shapes in this belt are such as show clearly the modeling action of the advancing ice sheet. The tendency in these features is to approximate forms offering the least resistance to the ice movement. (See Pl. XXV, *A* and *B*, p. 241.)

The change from the nearly featureless till plain at the north is gradual, though it takes place along a rather definite curved belt only a few miles in width. On the north the first evidence of the influence of the overriding glacier is the appearance of a slight fluting of the drift surface, forming scarcely perceptible, nearly parallel ridges a few feet in height. These gradually strengthen and are finally succeeded by ridges which attain a maximum height of 100 to 150 feet. Much of the general plain from which these rise is nearly flat and poorly drained, so that marshes occupy the spaces between many of them. The flatness of the intervening tracts emphasizes the boldness and abruptness of the larger ridges. A drive across the parts where these forms are most strongly developed impresses one with the unique character of the topography and arouses a question even in the mind of the layman as to its origin.

Southwestward from Beaver Dam Lake such topography continues for about 10 miles. The drumlins disappear along a northwest-southeast line passing through Columbus. Thence westward to the Wisconsin Valley the surface is a gently undulating plain with no definite features except certain drift-mantled erosion remnants. In this part the drift is rather more sandy than in the drumlin belt, as it is farther north.

South of Dodge County a well-developed drumlin topography spreads over Jefferson County and the part of Dane County within the Milton moraine.[2] In this part the drumlins are in general shorter and more nearly elliptical (Pl. XXVII). Near Rock River (Pl. XXVI) the elongated ridge forms continue southward, and east of Watertown these are closely crowded.

There are thus two partly distinct but coalescent main drumlin belts, a semicircular tract including nearly the whole south part of the glacial lobe south of latitude 43° N., lying mostly in Dane and Jefferson counties, and north of this a crescentic belt concave to the north, lying mostly in the southern half of Dodge County and extending thence west into adjacent parts of Columbia County and northeastward through Washington County into Fond du Lac County. In southern Dodge County the two belts merge so completely that probably they should be considered one in time and mode of development. Along the south and southwest margins of the southern tract drumlin formation was carried on to within 6½ to 13½ miles (average 9 miles) of the limit of the advance as marked by the outer margin of the Johnstown terminal moraine, and to an average of 7 miles from the inner margin of the moraine. On the east and southeast, where the free deployment of the ice was prevented by the opposing front of the Lake Michigan Glacier, drumlins occur within 1¼ to 7½ miles (average 5 miles) from the inner margin of the Kettle interlobate moraine. At the west side of the second belt drumlins give place to simple ground-moraine topography along a northwest-southeast line passing through Columbus. At the east, in

[1] Chamberlin, T. C., Geology of Wisconsin, vol. 1, p. 283, 1883. Also, Preliminary paper on the terminal moraine of the second glacial epoch: U. S. Geol. Survey Third Ann. Rept., p. 306, 1883. Also, An inventory of our glacial drift: Am. Assoc. Adv. Sci. Proc., vol. 35, p. 204, 1887. Also, Discussion sur le classification génétique de dépôts Pleistocènes: Cong. géol. internat. 5th sess., Compt. rend., p. 180, Washington, 1891. Also, Some questions respecting glacial phenomena about Madison [Abstract]: Am. Geologist, vol. 12, p. 176, 1893; refers to Buell's study of the drumlins. Also, Glacial phenomena in North America: The great ice age, by James Geikie, 3d ed., pp. 743-745, 1894. Also, Proposed genetic classification of Pleistocene glacial formations: Jour. Geology, vol. 2, pp. 521-523, 1894.

[2] Buell, I. M., Bowlder trains from the outcrops of the Waterloo quartzite area: Wisconsin Acad. Sci. Trans., vol. 10, pl. 13, 1895. Alden, W. C., The Delavan lobe of the Lake Michigan Glacier of the Wisconsin stage of glaciation and associated phenomena: U. S. Geol. Survey Prof. Paper 34, pls. 4, 5, 10, 13, 14, 1904; The drumlins of southeastern Wisconsin: U. S. Geol. Survey Bull. 273, 1905. See also the Hartford, Watertown, Whitewater, Stoughton, Madison, Sun Prairie, Waterloo, and Koshkonong topographic maps.

Washington County, the drumlins scatter out somewhat more indefinitely, in places grading off into slight flutings of the till surface and disappearing altogether within 5 to 10 miles of the interlobate moraine. West of the Niagara escarpment, in the Lake Winnebago-Rock River trough, the drumlins of the second belt have the elongated ridge forms noted above, as a result perhaps in some way of freer and more rapid movement along this axial trough. Above the Niagara escarpment these give place to the shorter elliptical forms, which in southern Fond du Lac County become shorter, broader, and higher, and in a few places assume approximately equiaxial domelike or mammillary shapes. (See Pl. XXIX, *B*, p. 254.) The relation suggests that the shortening of the forms may in some way be a consequence of the retarding influence of the Niagara escarpment on the overriding glacial flow.

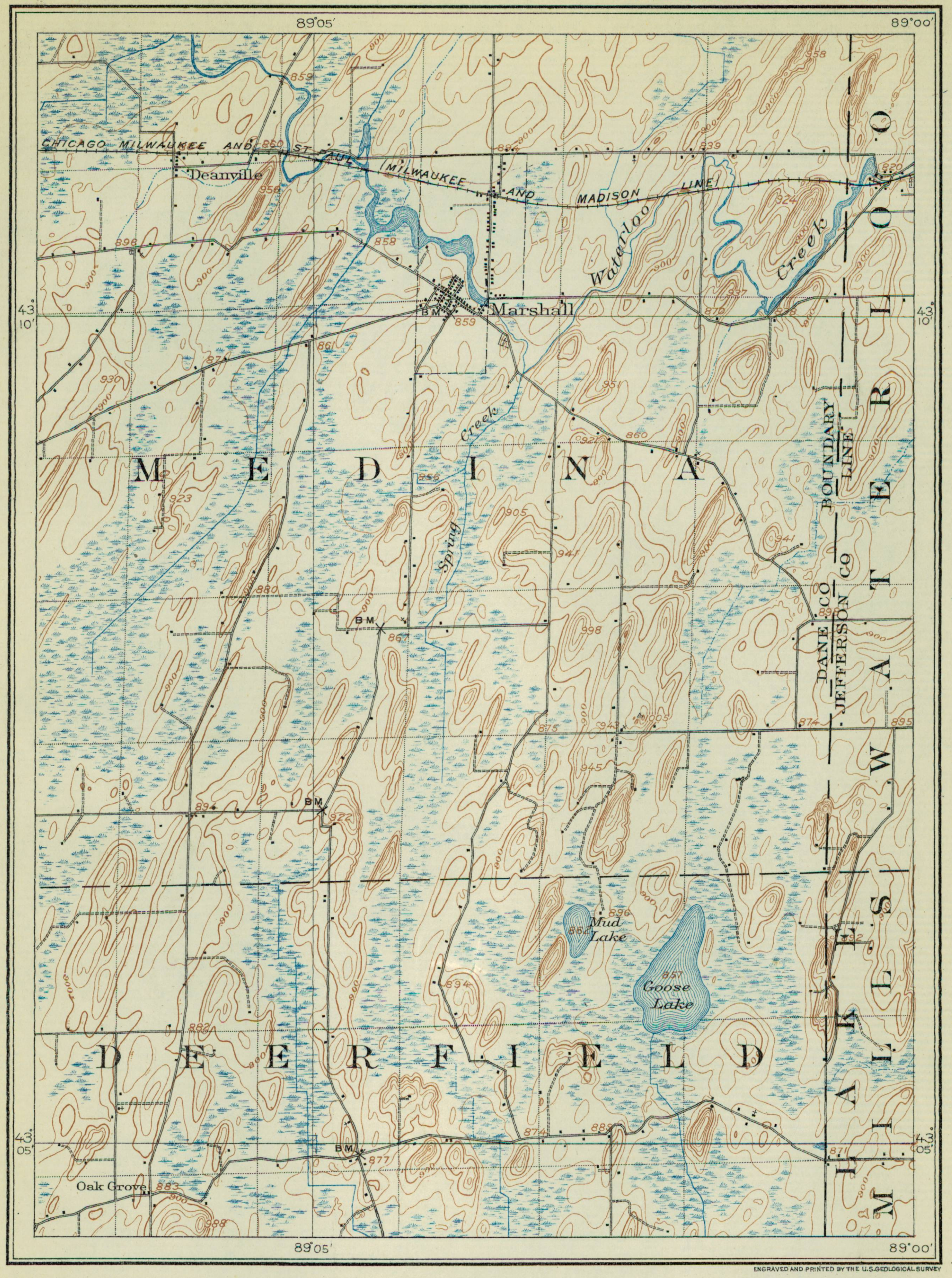
The featureless plain north of this drumlin belt and west of the Niagara escarpment is continued, or duplicated, on the upland above the escarpment in Oakfield, Leroy, Byron, Lomira, and Eden townships (Tps. 13 and 14, Rs. 16–18 E.), in a strip 4 to 7 miles in width between the crest of the ledge and the drumlin belt. In crossing this after ascending the bluff the ice exerted little or no molding influence on the drift. Northeastward from the railway in Eden the surface becomes more hilly though not showing well-shaped drumlins.

In the northeastern townships of Fond du Lac County a third remarkable drumlin belt is found. The topography of this tract is well illustrated by the southeastern part of the Fond du Lac topographic sheet of the United States Geological Survey, surveyed by H. L. MacDonald. (See Pl. XXVIII, p. 252.)

One of the most striking features of this drumlin group, which lies principally in Marshfield, Taycheedah, and Empire townships, Fond du Lac County, and in southern New Holstein Township, Calumet County, is that the axes of the hills do not radiate southeastward toward the Kettle interlobate moraine but trend southward or even somewhat west of south nearly parallel to both the escarpment and the Kettle moraine. It does not appear that ice moving in this direction above the escarpment would have contributed to the formation of the part of the Kettle moraine opposite these drumlins, for in other parts the direction of flow radiates until, as the limit is approached, it becomes nearly perpendicular to the trend of the moraine. The relation suggests that these drumlins were not formed when the ice was at its maximum stage but received their final molding when the glacier had so far thinned and shrunk that it extended perhaps no farther than to the moraine in Wayne and Theresa townships (T. 12 N., Rs. 17 and 8 E.), and that the ice in western Marshfield, Taycheedah, and Empire townships was compelled by the influence of the escarpment to a more southerly flow than when, being thicker, it radiated freely southeastward to the Kettle moraine. Intersecting striæ observed at several places in Taycheedah, Empire, Eden, and Byron suggest that an earlier and more southeasterly flow was followed by a more southerly one, which may have shaped the drumlins east and northeast of Fond du Lac.

Another noteworthy fact in this connection is that several southwest-trending drift ridges in the towns of Empire and Taycheedah have developed south-trending drumloidal crests which lie obliquely across them. (See Pl. XXVIII.) These ridges have about the same trend as the later recessional moraines which in places obscure the drumlin topography, and it may be that they were originally formed as such moraines when the ice front was retiring from its maximum advance. If such moraines were crossed obliquely by a later and more southerly readvance the result of the ice action on the ridges would probably be just what is seen here as a result either of remolding the previously deposited drift or of plastering more on to the obstructing ridges. Such a structure as that indicated by the log of the well at the Mount Calvary monastery certainly suggests morainal deposition for the original accumulation of the hill. In this well William Sealey, well driller, of Fond du Lac, penetrated 60 feet of what appeared to be a nearly solid mass of bowlders and beneath this 75 feet of sand and gravel. This hill has a relief of 137 feet above the marsh on the south and the underlying dolomite was reached at a depth of 135 feet from the surface, so that the whole bulk of the hill is of drift.

Still farther north in adjacent parts of Brothertown, Calumet, Charlestown, and New Holstein townships, there is a rather sparse development of drumlins and drumloidal flutings, which may perhaps be regarded as a



DRUMLIN TOPOGRAPHY IN EASTERN PART OF DANE COUNTY, WIS.

Scale $\frac{1}{62,500}$

1 ½ 0 1 2 Miles

Contour interval 20 feet.

Datum is mean sea level.

1917

House Doc. No. ; 64th Cong., 2d Sess.

fourth and distinct set. The axes in this group radiate normally to a small but, in part, well-marked terminal moraine, which curves southwest from Eaton Township to and along the escarpment east of Fond du Lac. Drumlins of the third set are surrounded and in places are partly buried by these morainal deposits, which are thus clearly of later origin. If the drumlins in these most northerly townships were formed at the same time as this moraine they must constitute a distinct and possibly a fourth set.

Structure and composition.—The drift comprising the ground moraine and drumlins over the limestone areas, so far as exposed to observation in natural and artificial exposures and so far as reported from wells, is principally rather compact, calcareous clayey till, light bluish below and oxidized to light buff or even brownish in the upper part. It evidently consists for the most part of fine rock flour from the abrasion of the Silurian and Ordovician limestones with perhaps a considerable ingredient of the sticky aluminous clay derived from the "Cincinnati" shale. Leaching in most places has not removed the lime carbonate from the compact till to a depth of more than 2 or 3 feet. In places, particularly where thin, it is composed very largely of coarse fragments of the underlying limestone.

Unobscured exposures afforded by cuts through drumlins along the line of the Chicago & Northwestern Railway in Dodge County, also by cuts which have been widened for double tracking along the line of the Chicago, Milwaukee & . Paul Railway in Dodge and Columbia counties, showed the light buff tint due to oxidation giving place to an unaltered bluish-gray color at depths of 8 to 20 feet. The bluish till is very compact, though not cemented, and was blasted to facilitate removal by steam shovel. Throughout a surficial zone 1 to 2 feet deep, which is oxidized brownish, the calcareous material is partly leached from the clayey matrix of the buff till, and the dolomite pebbles are largely removed or have had their surfaces roughly etched by solution. In places the brown zone is very thin at the crest of the ridge and gradually thickens down the side slope, as if weathered clay had been added to it by wash from above. Where this clay is 5 feet or more thick, its upper part is porous and exhibits vertical cleavage and other characteristics of loess.

As usual, more or less water-assorted sand and gravel is incorporated in local deposits in the ground-moraine drift. Where considerable deposits of sand and gravel alternate with clayey deposits (such, for example, as those shown by the following logs of G. C. Grimm's well in the southeastern part of Jefferson and Carl Becker's well at Fort Atkinson), the sand and gravel may represent assorted material laid down by fluvial or glacio-fluvial waters during more or less extended intervals of recession of the ice front, and the intervening clay beds may represent till sheets of the several readvances.

Glacial deposits penetrated by G. C. Grimm's well at Jefferson, Wis.

	Feet.
Blue clay	10
Sand and gravel	57
Blue clay	18
Sand and gravel	44
Blue clay	2
Yellow sand	10
Sand and gravel	6
Sand	12
Red sand	8
Total thickness of drift	167

Glacial deposits penetrated by Carl Becker's well at Fort Atkinson, Wis.

	Feet.
Clay	45
Sand Clay	55
Sand Clay	40
Sand Sticky blue clay	60
Sand Clay	33
Sand	30
Total thickness of drift	263

Beyond the limestone areas, in the parts of the ground-moraine tract where prior to the deposition of the drift the limestone covering was removed by erosion and the friable sandstones exposed to glacial action (Pl. I, in pocket), the drift is much more sandy, loose, and porous. Much limestone drift has been carried on over the sandstones, but the sand becomes more conspicuous in the drift as the distance from the limestone increases. So also considerable sand was carried from the tracts where the drift is immediately underlain by

St. Peter sandstone over the Lower Magnesian limestone areas. As a result the drift in the whole of the western half of the ground-moraine tract is more loose and sandy than in the eastern half. Northwest of the Lower Magnesian escarpment the drift is very sandy and the percentage of pebbles decreases. Estimates of the lithologic composition of the pebbles of the drift show more than 40 per cent limestone; yet in reality limestone pebbles are in much smaller proportion to the sand and other fine material of the till in this part of the area than over the limestone tracts, and in some exposures pebbles of any kind are present in but small amounts.

In the area of the preglacial Wisconsin and Fox River valleys, where most of the drift exposed at the surface is very sandy, there are considerable deposits of reddish clay, which are to be distinguished from the ground moraine and which require somewhat particular discussion.

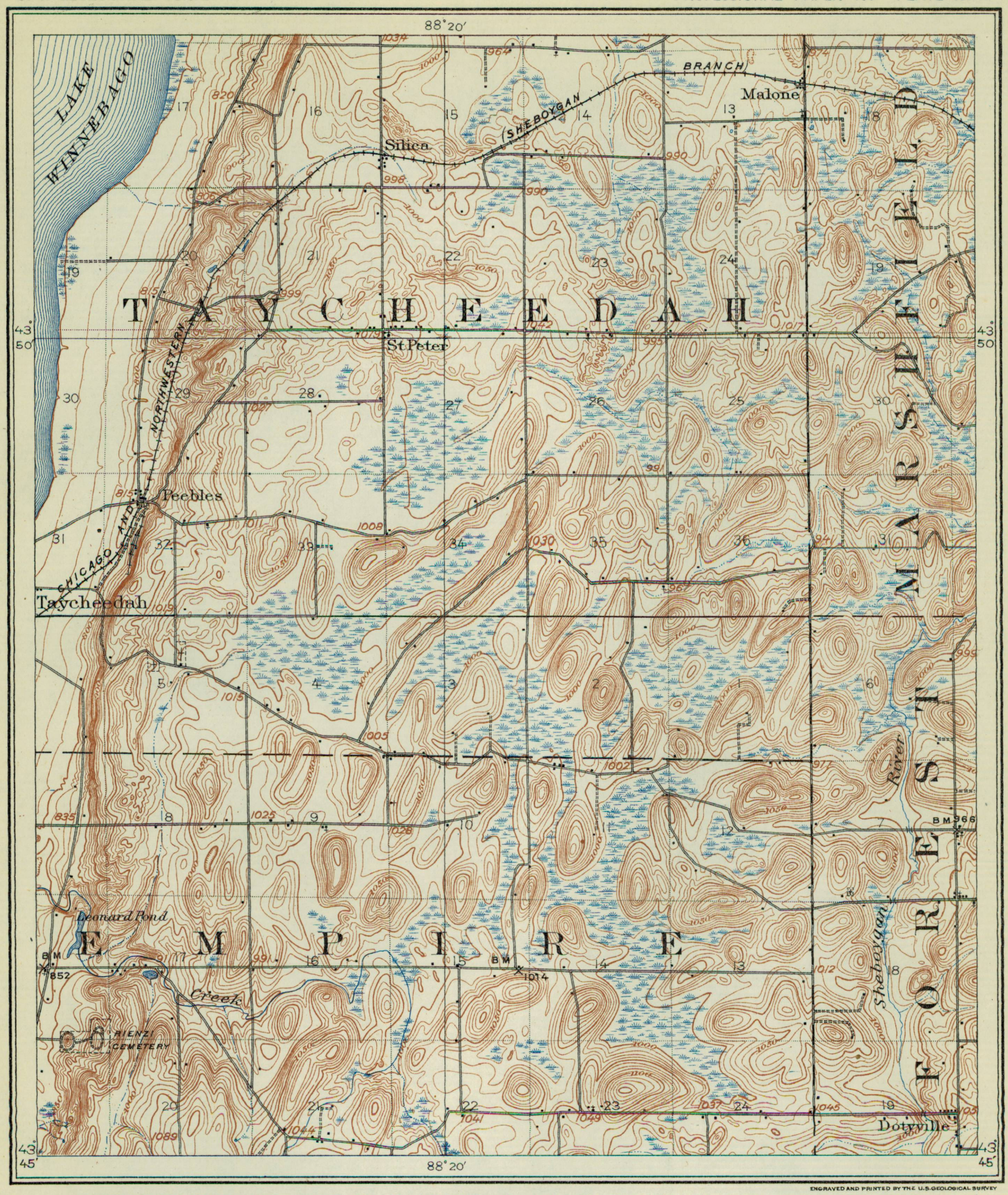
Thickness of drift.—An effort has been made to ascertain as nearly as could be done the average thickness of the drift throughout the ground-moraine tract. The results obtained are based on an extended and detailed study of the relations of the drift to the preglacial topography and from the correlation of data concerning more than 1,100 outcrops of the bedrock, more than 2,500 wells that reached rock, and more than 1,300 wells that did not penetrate the full thickness of the drift. The wells and rock outcrops are scattered over a ground-moraine area of more than 4,000 square miles, so that the estimate can of course be taken only as indicating with some degree of approximation the actual amount of drift present. This thickness includes not only the deposits of the last glacial advance but generally whatever of earlier glacial, fluviatile, and lacustrine deposits remain buried but not incorporated into the later drift. The full amount of the filling in the preglacial Wisconsin and Fox River valleys is not included in this estimate, as these valleys are known to contain considerable amounts of water-laid drift.

The estimated average thickness through the north-central part of the area, 1,831 square miles, included principally in the western half of Fond du Lac County and in Dodge County, is about 30 feet. Between this and the interlobate moraine on the east lying principally on the Niagara dolomite upland southward to latitude 43° 30′ N. the average over 392 square miles is about 28 feet. Southward in the Hartford and Oconomowoc region the drift, which is thin in places on the upland, thickens greatly over the lower land, so that the average over 50 square miles rises to 67 feet. Thence westward across the south part of the tract, that lying principally in Jefferson and Dane counties, the average thickness over 1,367 square miles is a little more than 63 feet. Here the amount of filling in the preglacial valleys of Rock River and its tributaries is considerable and undoubtedly includes much drift of earlier origin. Northward from Dane County through the western part of the area the estimated average thickness drops to 33 feet. As stated above, not all the filling of the preglacial Wisconsin and Fox River valleys is included in this amount. The total estimated average thickness over 4,072 square miles of the ground moraine is 42 feet.

The estimated average thickness (see p. 217) throughout 111 miles of the Johnstown moraine, extending from Richmond on the south to New Chester Township on the northwest, is 106 feet. The terminal moraine has an average width of not more than 2 miles, so that though the drift concentrated along this belt is much the thicker the total amount spread out as ground moraine is vastly the greater. It is quite probable also that in the peripheral parts of the tract, over which the ice was much thinned by melting and where the movement was less vigorous, much more of the earlier drift continued, not incorporated with the succeeding deposits.

Lithologic composition.—Over the limestone areas the drift is composed predominantly of material derived from these formations. At many places in the north-central part of the area, where the glacial deposit is thin, 97 to 99 per cent of the pebbles are from the immediately underlying limestone, and at some places rather careful search is needed to find even a few crystalline pebbles. Almost or quite universally, however, foreign material is present, though in subordinate amounts.

Many rough analyses made by counting and sorting pebbles give some interesting results. In the north-central part of the area the average of analyses made at 17 different places



DRUMLIN TOPOGRAPHY IN EASTERN PART OF FOND DU LAC COUNTY, WIS.

Scale $\frac{1}{62,500}$

1 ½ 0 1 2 Miles

Contour interval 10 feet.

Datum is mean sea level.

1917

House Doc. No. ; 64th Cong., 2d Sess.

shows 96.4 per cent of the pebbles to be from the local limestones with small percentages of local sandstones and cherts and only 3.6 per cent of foreign material from the crystalline rocks of Canada. Four analyses made at cuts in drumlins showed 90.88 per cent mostly local limestone and 9.12 foreign crystallines. Fifteen analyses in the eastern part of the tract showed 90.27 per cent mostly limestone and 9.73 per cent foreign crystallines. Four analyses in drumlin drift showed 90.6 per cent local material and 9.4 per cent foreign. In the tract south of latitude 43° 15′ N., mostly in Jefferson and Dane counties, 20 analyses showed 88.6 per cent local material and 11.4 foreign crystallines; and 28 estimates at cuts in drumlins showed 90.9 per cent local and 9.1 per cent foreign. In the analyses made in the north-central and eastern parts of the ground moraine pebbles of quartzite were rarely found. In the southern part of the ground moraine, such pebbles begin to appear in the longitude of Whitewater and Watertown and are present at almost all points westward to the Madison region. They are most abundant in the area of the latest bowlder fans heading in the Waterloo quartzite ledges. The local quartzite is present in the drumloidal drift as well as in other parts of the ground moraine and in several analyses constituted 15 per cent or more of the pebbles. Quartzite pebbles found west of the tract traversed by the last ice which crossed the Waterloo ledges are believed (see p. 163) to have been given a more westerly distribution by ice of earlier glaciers, the ice moving first westward and later southwestward across the ledges.[1]

North of the Madison region, in the western part of the ground-moraine area, 34 analyses showed an average of about 78 per cent limestone mostly Lower Magnesian, 3 per cent of cherts, about 9 per cent of sandstone pebbles, and 10.3 per cent of crystallines, which probably include some pebbles from local crystalline ledges but which consist mostly of crystallines foreign to Wisconsin but native to Canada.

It appears then that 36 analyses of the drift exposed in sections of the drumlins showed 90.9 per cent of the pebbles to be of local derivation and 9.1 per cent from the crystalline rocks of Canada; and that 86 analyses of drift from the ground moraine showed the same percentages. The final averages for the total 122 estimates were therefore 90.9 per cent local and 9.1 per cent foreign.

Comparison of the above percentages indicates that, so far as can be judged from the pebbles, there is no essential difference in lithologic composition between the drift comprising the drumlins and that of other parts of the ground moraine. There seems to be a slight increase in the percentages of foreign material in passing from the north-central part of the ground-moraine tract outward and into the terminal. However, the relatively high percentage of crystallines, 17 per cent (see p. 221), shown by analyses in the terminal moraine along the west side of the glacier is due not only to the presence of crystalline pebbles of local derivation, which were not always accurately discriminated, but also in large part to the falling off in the limestone pebbles there, with the increasing contribution from the local sandstones, which, being represented more in the finer material of the drift than the pebbles, is not correctly shown by these analyses. The 10 per cent of foreign material shown by the 27 analyses along the moraine encircling the south end of the lobe area is perhaps more nearly correct, as the limestone constituent is more normally represented. This 10 per cent, though considerably higher than the 3.6 per cent foreign pebbles of the north-central part of the ground-moraine tract, is not much higher than the final average of 9.1 per cent foreign material for the whole ground-moraine tract. The Kettle interlobate moraine on the east contains a considerably larger foreign ingredient, average percentages ranging from 10 per cent at the north to 15.99 per cent at the south, with a final average for 34 estimates of 12.52 per cent. The drift of the Lake Michigan Glacier generally carries a little higher percentage of foreign material than does that of the Green Bay Glacier, and the higher percentages in the interlobate moraine may be in part due to the larger contribution by the collaborating glacier on the east.

DRUMLINS.

Typical forms.—The writer prefers to restrict the name drumlin to those drift hills which show clearly the molding effect of the advancing ice. The typical drumlin of southeastern

[1] Buell, I. M., Bowlder trains from the outcrops of the Waterloo quartzite area: Wisconsin Acad. Sci. Trans., vol. 10, pp. 500-504, 1895.

Wisconsin may be said to be a hill of glacial drift which approximates the form of a segment of an elongated ovoid, of which the widest part of the basal outline and the highest point of the crest are generally not more distant from the stoss end than one-third the length of the major axis, and whose major axis is oriented parallel to the direction of the movement of the glacier which formed it. From this type the forms vary on the one hand to elongated narrow ridges, some of which attain lengths of 3 to 4 miles, and on the other hand to nearly equiaxial dome-shaped or mammillary hills. Exceptional variations are double-tailed and double and triple crested forms, and ridges with subordinate crests overlapping in echelon. The longer forms were developed principally in the region of axial movement of the glacier and in the tract west of the Niagara escarpment, where there was good opportunity for the incorporation of sticky aluminous clay derived from the Cincinnati shale. The presence of the adhesive clay doubtless facilitated the building up of drumlins by the plastering-on process, and the elongation of the forms may be some function of the more rapid movement along the Winnebago-Rock River trough. There is a general shortening of the forms progressively toward the limit of the advance, where the rate of flow was retarded owing to the thinning and wide radial spreading of the moving ice. The shortening of the forms on the upland east of the Niagara escarpment may be due to the retarding effect of this escarpment on the ice overriding it in addition to that resulting from thinning and radial spreading.

Numerous instances have been seen where it appeared that the melting of the ice left piles

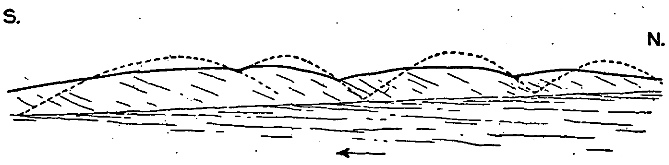


FIGURE 15.—Profile of a long, narrow drumloidal ridge with undulating crest 3 miles north of Clyman, Dodge County, Wis. Apparently due to blending of hillocks of drift by the overriding glacier.

of drift unfinished in all the various stages of modeling. Some small knolls of stony drift have no definite arrangement; others are aligned parallel to neighboring drumlin axes and partly blended with each other. In the next stage the piles are larger and are blended into a continuous ridge but have a crest line that undulates over the successive tops and intervening hollows. (See figs. 15 and 16.)

FIGURE 16.—Profile of long unfinished tail of a drumlin in the W. ½ sec. 35, T. 10 N., R. 15 E., 2 miles southeast of Clyman, Dodge County, Wis. Apparently due to blending of hillocks of drift by the overriding glacier.

Others, more advanced, are so far smoothed and blended as to show only slight sags in their crest lines. From this it is but a step to the completed form of the elongated drumlin, where all irregularities of slope and crest have been smoothed away, giving the beautifully symmetrical form, with the tail tapering gradually in the direction of the ice advance.[1]

Structure.—With but few exceptions the partial sections of drumlins seen by the writer expose compact structureless clayey till like that composing most of the rest of the ground-moraine deposit over the limestone areas. In some places the till is semistratified, with somewhat indefinite bands that curve conformably with the surface contours and suggest that the hill has been built up by the addition of more or less definite layers.

Layers of stratified sand and gravel or stoneless silt are exposed in sections of few drumlins. These are in some cases folded, and it is not clear that they have any definite relation to the drumlin structure as such.

A fairly definite cleavage in the clayey matrix of the till developed parallel to the curved surface suggests the effects of pressure of the overriding ice but may in reality be the result of successive additions of thin layers of adhesive clayey material. (See Pl. XXIX, *A*.) Evidence indicating the absence of rock cores from the drumlins has been collected throughout the whole drumlin area.[2]

Lithologic composition.—Estimates based on pebbles collected from drift composing drumlins show (see p. 253)

[1] For a possible instance of such drumlin modeling by an existing glacier see the following: Chamberlin, T. C., Glacial studies in Greenland: Geol. Soc. America Bull., vol. 6, p. 216, 1895. Also Glacial studies in Greenland: Jour. Geology, vol. 3, pp. 478-480, 1895.

[2] Alden, W. C., The drumlins of southeastern Wisconsin: U. S. Geol. Survey Bull. 273, pp. 25-27, 1905.

that about 91 per cent of the coarser material is of local derivation. If the analyses included also the finer material comprising the matrix of the till the percentage of local material present might be found to be even larger. This high percentage of local material indicates that the drumlins are composed of drift accumulated at or near the base of the ice and transported for comparatively short distances. Observations made by Buell and cited by Chamberlin,[1] and similar observations made by the present writer[2] on the percentage of quartzite in the drift in the lee of the quartzite ledges of the Waterloo region, show that local quartzite material was incorporated in the drumlins in considerable amounts within short distances of the ledges and decreased therefrom southward to the limit of the ice advance. The results of Buell's observations led Chamberlin[3] to make the following statement:

As the drumlins bear evidence of gradual accretion it seems necessary to suppose that they were built up by successive additions of material derived from a stream of drift passing over the quartzite ledges and making constant additions from them.

Buell's observations on the distribution of the quartzite drift within and on the surface of the drift and on the amounts of abrasion which the fragments had suffered led Chamberlin to the further conclusion stated as follows:[1]

The combined testimony of the foregoing facts seems to me quite decisive in its bearing on the proposition that the derivation, transportation, and deposit of the quartzite bowlders was almost exclusively subglacial or at least closely basal. As these bowlders enter into the structure of the drumlins from base to summit, and are mingled with much other local material, the foreign element being relatively small, they seem to compel the same conclusion respecting the whole of the material which was built into the drumlin forms.

From Buell's determination that the material derived from the quartzite ledges by the first glacier crossing them was carried westward, and that the fragments derived by a succeeding ice movement were carried southwestward, Chamberlin was led to the following conclusion:[1]

This has a double bearing upon the question of the origin of the drumlins in that it indicates basal transportation in both epochs and in fact that it indicates direct accumulation of the drumlins *de novo* during the later incursion. It seems to exclude the view that the drumlins are remnants of the older drift; for, since the older train was westerly, there would be no quartzite material in the old drift lying southwesterly from the outcrops, and hence none would appear within the body of the drift in that region when worn into drumlin forms.

Distribution.—The drumlins were formed (Pl. III, in pocket) in those parts of the area of the Green Bay Glacier where the lines of movement were radiating very notably as the ice spread to the curved margin of the lobe. The lines of movement bounding any drumlin-forming segment of this glacier from the north limit of the drumlins in the area of that segment to the peripheral margin of the lobe show that the amount of this spreading is very considerable—much greater than that which took place in similar segments of the glacier of equal initial width but within whose area no, or few, drumlins were formed. This relation gives rise to the suggestion that radiation was an important factor in drumlin formation.[4] Chamberlin has suggested that their formation may be in some way related to longitudinal crevassing.[5]

The writer has attempted to compute the amount of this radial spreading from the trend of striæ and drumlins and from the estimated thickness of ice necessary to enable the glacier to move over the particular land surface and to reach the limit of its advance with a marginal thickness such as that indicated by the phenomena on the Baraboo quartzite bluffs. The results of the computations are not entirely conclusive, and possibly the writer has used a somewhat doubtful and unnecessary specialization by regarding the drumlins of the area as having been formed in three distinct sets correlated with advances of the ice to three distinct sets of marginal morainal deposits. It seems probable, however, that these qualifications do not entirely vitiate the results, which taken as a whole afford a reasonable basis for an hypothesis which may be stated as follows: The ice of the drumlin-forming segments of the Green Bay Glacier was moving and spreading under conditions which developed stresses along transverse lines; and these stresses, though perhaps not causing the actual opening of longitudinal crevasses, facilitated the spread-

[1] Chamberlin, T. C., The horizon of drumlin, osar, and kame formation: Jour. Geology, vol. 1, pp. 259-264, 1893.

[2] Alden, W. C., op. cit., pp. 37, 38, 42.

[3] Op. cit., pp. 259-260.

[4] Alden, W. C., Radiation of glacial flow as a factor in drumlin formation: [Abstract] Geol. Soc. America Bull., vol. 22, pp. 733-734, 1910.

[5] Chamberlin, T. C., Personal communication to Alden, W. C., The drumlins of southeastern Wisconsin; U. S. Geol. Survey Bull. 273, p. 43, 1905. Chamberlin, T. C., and Salisbury, R. D., Geology, vol. 3, p. 361, 1906.

ing of the basal ice about obstructing piles of drift and their formation into drumlins rather than their obliteration by erosion. This condition may also have induced localized deposition in piles or ridges which later were shaped and perhaps added to by the plastering on of drift.

Theories of formation.—Chamberlin and Salisbury[1] summarize the different views on the origin of drumlins as follows:

> The origin of drumlins has been much discussed, but there is as yet no generally accepted conclusion, and the subject is still under active inquiry. Opinion is chiefly divided between the views (1) that they were accumulated beneath the ice under special conditions and (2) that they were developed by the erosion of earlier aggregations of drift, much as roches moutonnées are developed. Under the first of these general views, it has been suggested (1) that the bars of rivers give the clue to the origin; (2) that protuberances of rock gave occasion for the lodgment; (3) that the balance between load and strength of movement furnishes the key to their explanation, a slight but not excessive overload being the condition necessary for their development; and (4) that they may be, in some way, connected with longitudinal crevasses.

To this is appended a list of papers on drumlins.

In an excellent paper on the drumlins of central-western New York[2] H. L. Fairchild makes the following statement concerning what he regards as the key to drumlin formation in that area:

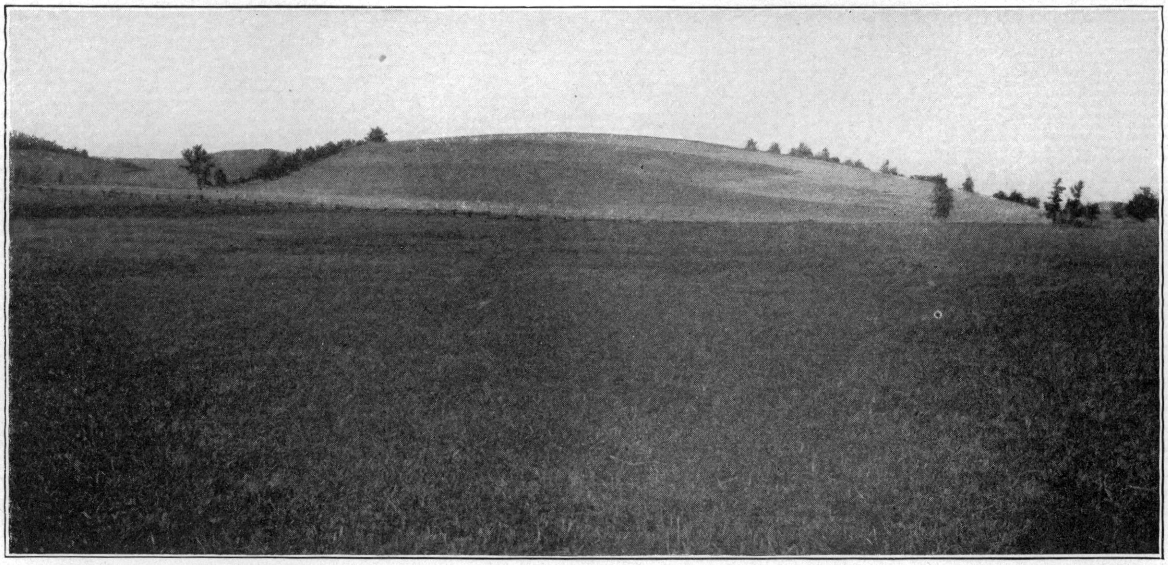
> Drumlins are shaped by the sliding movement of the lowest ice, that in contact with the land surface. This fact implies that the whole thickness of the ice sheet participated in the motion. Such motion was not due to gravitational stress on the ice mass over the drumlin area, because the general slope of the drumlin area is up hill; but was produced by an effective thrust on the marginal ice by the pressure of the rearward mass. As the ice sheet thinned by ablation there came a time when the drift-loaded ice in contact with the ground was subjected to less vertical pressure and to relatively greater horizontal pressure by the deep ice in the rear, and was pushed forward bodily. In this fact is believed to lie the key to drumlin formation.

If this is a true explanation it applies well to the drumlins of the Green Bay Glacier. The present writer's computations of the relative areas of several cross sections of the drumlin-forming segments indicate that while the ice was spreading and thinning in these parts of the lobe each drumlin-forming segment was actually increasing in volume though not receiving lateral contribution from adjacent segments. This could result only from the forward crowding of more rapidly moving ice in the rear. Such conditions might favor bodily thrust of the spreading ice which was lagging under increased friction. Such mass movement would be in addition to whatever normal internal movement was taking place in the ice.

[1] Geology, vol. 3, pp. 360-361, 1906.

[2] Fairchild, H. L., Drumlins of central-western New York: New York State Mus. Bull. 408, pp. 429-430, 1907.

A. SECTION OF PART OF DRUMLIN 5 MILES NORTHEAST OF WATERLOO, WIS., SHOWING CLEAVAGE DEVELOPED IN CLAY MATRIX OF THE TILL.



B. TRANSVERSE PROFILE OF DOME-SHAPED DRUMLIN 9 MILES SOUTHEAST OF FOND DU LAC, WIS.

CHAPTER IX.—DEGLACIATION.

GENERAL CHARACTER OF THE PROCESS.

The disappearance of the later Wisconsin glaciers was not the result of one uninterrupted period of melting. There were not only the ordinary seasonal variations of temperature but there seem to have been several variations of much larger magnitude, embracing in all probability long periods of years, if not of centuries. During the warmer periods the rate of melting exceeded the average rate of accumulations, so that the glacial margins retreated. During the cooler periods the ratio was reversed and the glaciers recovered some of the territory previously abandoned. On the whole the readvances were less extensive than the marginal retreats, so that in course of time the region came to be wholly freed from ice. The limits of several of these oscillations are indicated by belts of morainal deposits looped across the area within the outer moraines. Some parts of these moraines are, in places, comparable in bulk with the outer moraines, but most of them are much less conspicuous. Some are so patchy that they were not recognized as marking positions of halt of the ice front until their delineation on a map showed them to be grouped more or less definitely in concentric belts corresponding with what must have been successive positions of the contracting glacier margins. There is a general correspondence in the number and, to some degree, also in the spacing of the moraines of the Green Bay and Lake Michigan glaciers, including the Delavan lobe, which supports the correlations made by the present writer. This is not, however, so clearly marked as to exclude all difference of opinion as to the interpretation.

In the following discussion the correlated moraines and attendant phenomena of the two glaciers are treated as marking the culminations of more or less definite readvances following successive marginal retreats of unknown, but probably somewhat greater, extent, the net result of the oscillatory process being the gradual deglaciation of the region. At each of these stages the disposition of the glacial waters flowing from the melting ice and the character and distribution of the deposits made by them were very important factors in the development of the present topography. These phenomena and also conditions in the interlobate belt are considered for each successive stage.

The general process of deglaciation of the area comprises therefore the recession to the Milton and Elkhorn moraines; the recession to the Lake Mills morainic system and correlated recession of the Delavan lobe; later recession of the Green Bay Glacier to the Green Lake, Waupun, Rush Lake, and St. Anna moraine and the development of the correlated moraines of the Lake Border morainic system of the Lake Michigan Glacier; and finally the deposition of the red till and associated lacustrine deposits.

RECESSION TO THE MILTON AND ELKHORN MORAINES.

GENERAL RELATIONS OF THE MORAINES.

The process of deglaciation of the area appears to have begun with the melting back of the south front of the Delavan lobe from the Genoa moraine, but the retreat of the ice fronts did not become general until the completion of the Darien and Johnstown moraines. When this was accomplished the front of the Green Bay Glacier withdrew from the Johnstown moraine, and that of the Delavan lobe abandoned the Darien moraine. Whether there was a considerable retreat followed by a readvance to the position of the inner moraines, or whether the intervals of a few miles between the inner and outer moraines mark the full extent of the wasting of the glaciers at this time, is not known.[1]

If the melting back of the south front of the Delavan lobe from the Genoa moraine to the

[1] The relations of the several moraines, terraces, and outlets for glacial waters of the Green Bay and Delavan lobes are delineated in U. S. Geol. Survey Prof. Paper 34, pls. 4, 5, 10, 13, 14, 1904.

Darien moraine be regarded as a preliminary stage in the deglaciation, the close of the first main stage would be indicated by the formation of the Elkhorn moraine of the Delavan lobe and the Milton moraine of the Green Bay Glacier. The distribution of these moraines is shown on Plate III (in pocket).

The net recession of the ice front, or shrinkage of the Green Bay Glacier, indicated by the Milton moraine—that is, the distance from the outer margin of the Johnstown moraine to the inner margin of the Milton moraine—is generally 6 to 9 miles. As shown by the distribution of the moraine, however, this shrinkage was confined to the south end and west side of the lobe. On the east the ice appears to have continued pressed snugly against the Kettle interlobate moraine. South of Whitewater, within 10 miles of the interlobate angle formed by the junction of the Milton and Elkhorn moraines, the net recession of the ice front was less than 4 miles. In the basin between the Baraboo quartzite ranges the recession was 12 miles and to the north in Adams and Marquette counties it was 5 to 8 miles. The splitting up of the moraine along the west side of the glacier would seem to indicate more oscillation along this western front than at the south end.

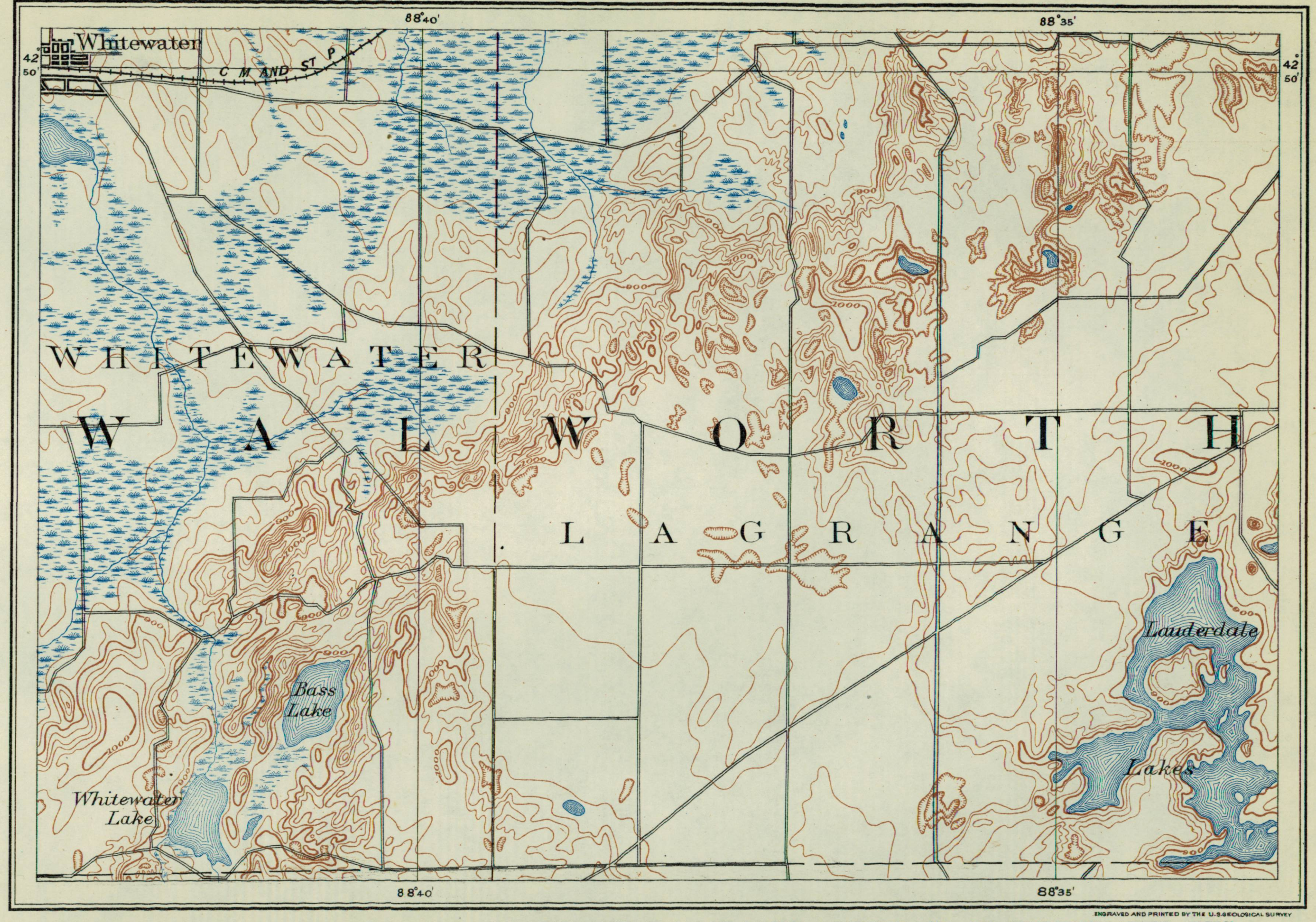
ELKHORN MORAINE.

Topography.—The Elkhorn moraine takes its name from its relation to the city of Elkhorn. West of Elkhorn it consists of an outer and an inner belt, the inner and more prominent ranging in width from one-half mile to 2 miles and having a relief above the adjacent ground moraine of 20 to 60 feet. The surface is generally pitted with shallow depressions and some sharper kettle holes and gravel knolls. To the south, beyond the valley of Jackson Creek, the moraine rises and (see p. 184) appears to cross the northern extension of Marengo Ridge. A belt of gravel knolls and kettle holes descends from this elevated tract, crosses the sag between the heads of Lake Como and Williams Bay and can be traced for 2 miles along the crest and northern slope of the bulky ridge separating the lake basins. A belt of similar morainal character extends eastward from this same elevated tract along the slope forming the north side of the Como Lake basin.

Morainal characters are shown by the bulky ridges both on the north and south of the valley occupied by Lake Como and Como Creek. To the east, on the north and south sides of the White River valley, these ridges connect with interrupted areas of knob and kettle topography, which in turn merge into those of the inner part of the Darien moraine. Near the line between Walworth and Racine counties the combined moraine swings northeastward toward Burlington, where the knob and kettle topography is very strongly developed.

The bulky ridges between Springfield and White River and between Geneva and Como lakes are very largely of till. Of the wells drilled on the ridge north of Lake Geneva three are said not to reach rock at depths of 270, 285, and 317 feet; the deepest of these penetrated only compact clay till. It is not thought that the whole bulk of these ridges belongs to the Elkhorn morainal deposit; probably most of the drift was of earlier deposition. Numerous exposures along the crests and slopes of the ridges to the northeast show gravel; in T. 2 N., R. 18 E. (Lyons Township) where kames and kettles take the place of the bulky ridges, they show almost entirely gravel. These gravel deposits are generally coated with clay and humus, but upon the more abrupt knolls and steeper slopes the soil is very thin.

At the time of the formation of the Elkhorn moraine the point of junction of the fronts of the Delavan lobe and Green Bay Glacier had been removed to the vicinity of the village of La Grange, 9 miles northeast of its former location. This position allowed the outwash from a frontage of 3 miles of the Green Bay Glacier to be discharged into the low area behind the Darien moraine, where it commingled with that of the Delavan lobe and built up the outwash deposit of gravel and sand in the towns of La Grange and Sugar Creek. On the further withdrawal of the Delavan ice front the area behind the Elkhorn moraine and between the Kettle interlobate moraine and the Sugar Creek valley was also filled with outwash deposits, which so far buried the Elkhorn morainal deposits that only the higher parts rise above the outwash plain and can be distinguished therefrom. Besides having greater elevation the higher morainal tracts are distinguished from the surrounding outwash by their undulating surfaces, by their content of till, and by the bowlders on their surfaces, bowlders being absent from the sur-



ENGRAVED AND PRINTED BY THE U.S.GEOLOGICAL SURVEY

TERMINAL MORAINE AND OUTWASH TERRACE TOPOGRAPHY SOUTHEAST OF WHITEWATER, WIS.

Terminal moraine ridge crosses area diagonally from southwest to northeast, and the outwash terrace is the flat area to the southeast

Scale $\frac{1}{62500}$

1 ½ 0 1 2 3 Miles

Contour interval 20 feet.

1917

rounding plain. The burial of great masses of ice, whose subsequent melting formed the basins of Otter, Lauderdale, and Pleasant lakes, occurred at this time.

Lithologic composition.—The results of estimates at 27 surficial exposures scattered along this moraine from the town of Palmyra to the town of Burlington show the composition of the drift to be very much the same as in the Darien moraine. Of the material examined all but about 18 per cent appeared to be of local derivation, 64 per cent being from the Niagara dolomite. At no exposure was more than 25 per cent of foreign material found, though the crystallines, sandstones, and quartzites were all regarded as of foreign derivation. The average percentage of the first was 16.62 and that of the last 0.13.

In the morainal deposits near Burlington a $2\frac{1}{16}$-carat diamond was found many years ago. This is one of the rare occurrences of diamonds in Wisconsin. (See pp. 221, 270, 301, 308.)

MILTON MORAINE.

Relations.—Lying within the Johnstown moraine, nearly parallel to it and separated from its inner border by a space averaging about 2 miles in width, is an inner morainal belt marking the first stage of halt in the wasting of the Green Bay Glacier. From the strong development in the town of Milton and its relation to the villages of Milton and Milton Junction, it has been found convenient to refer to this moraine as the Milton moraine. Its formation appears to have been contemporaneous with that of the Elkhorn moraine.

That part of the Kettle interlobate moraine extending from the junction with the Elkhorn moraine near the village of Lagrange southwestward to a point about a mile north of Bass Lake, though doubtless begun as an interlobate moraine while the Darien and Johnstown moraines were being formed, was completed as a part of the Milton moraine. This is shown by the relations of the gravel terrace bordering it on the south. (See Pl. XXX.) North of Bass Lake this moraine joins a complicated morainal tract at the north end of the interlobate deposit resulting from the coalescence of the Darien and Johnstown moraines. Lying across the north end of this interlobate tract, the Milton moraine continues, with two narrow breaks, to the point of its distinct separation from the earlier moraines.

Distribution and topography.—North of Bass Lake the moraine is composed of a single bulky ridge, with a relief of nearly 150 feet on the south. This relief is probably due to the continuance of considerable masses of ice in the angle between Johnstown and Milton moraines, which prevented the filling of the area with outwash. In southwestern T. 4 N., R. 15 E. (Whitewater Township), the moraine is narrow and ridgelike, with a rather abrupt ice-contact face rising 80 to 200 feet above the marshes on the north. The slopes and crest are generally pitted with kettle holes and the outer front, except in the vicinity of Bass and Whitewater lakes, is bordered by an outwash terrace, above which the undulating crest of the moraine rises 15 to 60 feet.

Westward to Rock River the moraine is broader and less abrupt. From a narrow ridge it spreads out to a belt varying in width from 1 to 3 miles. The surface is marked here and there by sharply knobbed and pitted areas, but for the most part the topography is one of gentle sags and swells with inclosed marshy depressions. One of the most sharply pitted areas lies about 4 miles southwest of the village of Whitewater. Where the moraine crosses the preglacial Rock River valley in T. 4 N., R. 13 E. (Milton Township), the irregularities of the surface indicate the burial of very much ice. A notably large depression is that containing Cedar Lake, $1\frac{1}{2}$ miles northwest of Milton Junction. It has a length of $2\frac{1}{2}$ miles, a breadth of one-eighth to one-half mile, and a depth of 60 feet or more.

Some of the hills in the northeastern part of Milton Township, though lying within this terminal belt, have the form and trend of drumlins. It is probable that they are a continuation of the drumloidal topography on the northeast and east which was developed during the advance of the ice and was later modified by the superposition of morainal deposits. Immediately north of this moraine is the shallow basin of Lake Koshkonong, which is due to the damming of the preglacial valley by the morainal deposits. After the ice abandoned the Milton moraine this basin became flooded.

Between Rock River and Edgerton the morainal topography is well marked, being pitted with great kettles holes, but from this place to Stoughton the limits of the morainal belt, which is marked by slight sags and swells, are poorly defined. The reason for this is probably that the bulk of the deposits was taken up in filling the preglacial valley of the Yaharah. (See pp. 116–118.) Numerous wells along this part of the moraine penetrate 100 to 275 feet of drift without reaching the rock bottom of the ancient valley, though to the east and to the west limestone and sandstone are exposed at the surface or encountered in wells at much less depth. In the western part of T. 5 N., R. 11 E. (Dunkirk Township), the southwest or outer margin of the moraine becomes more definite though of but slight relief, and thence northwest through most of the distance to the line of the Chicago, Milwaukee & St. Paul Railway is bordered by a flat terrace which slopes gently to the marsh along Badfish Creek. To the west between the Chicago & Northwestern and Chicago, Milwaukee & St. Paul railways the morainal belt narrows from nearly 5 miles to less than 1 mile. The topography is generally marked by slight sags and swells, but in places, as southwest of Lake Kegonsa, kame and kettle topography is finely developed.

When the glacial front occupied the Milton moraine the glacial waters, escaping through a sag in the crest of the Johnstown moraine, extended Rock River northward and initiated Yaharah River and Badfish Creek. A flat tract 1 to 2 miles southwest of Edgerton appears to be a small outwash terrace formed before the streams had greatly eroded the outlet.

In T. 6 N., R. 9 E. (Fitchburg Township), the Milton moraine lies across rock ridges and three intervening buried valleys tributary to the ancient Yaharah. Here, between the two lines of the Chicago & Northwestern Railway, the moraine is well marked as a ridged and pitted belt one-half to three-fourths mile wide.

From the head of Nine Springs Marsh northwestward and then northward into Adams County the Milton moraine is divided into two to four more or less distinct belts of mild morainal topography, distributed over a belt 3 to 6 miles in breadth, that mark gradual withdrawals from the outer line. From Middleton Township to Wisconsin River these morainal deposits alternately coalesce and separate, as shown in Plate III (in pocket). These deposits are traversed for nearly 4 miles by the road leading westward from Madison to the Lutheran Church 2 miles southwest of Middleton. The moraine is marked in part by more or less definite ridging of the drift but principally by the mild sag-and-swell topography. The ice front first lay across the Black Earth Valley at the more easterly of the two hills in the middle of the valley 3 miles west of Middleton. From this position it was melted back about a mile to where drift is piled in the valley, then again about a mile to the ridges (from which gravels are taken) near the railway a mile west of the village. A third recession carried the ice front back to Pheasant Branch near the head of the Mendota basin.

The several morainal belts are not very readily traceable across the dissected upland of the Lower Magnesian limestone between the Black Earth and Wisconsin valleys. The boundaries of the tracts are very indefinite. No continuous ridging is found, and, in large part, only the mild sags and swells distinguish the topography from that of the intervening ground-moraine tracts, the bulk of the deposits being taken up in filling the preglacial valleys, in some of which thicknesses of 100 feet or more of drift are found.

In a few places the moraines form conspicuous topographic features, among which may be noted the ridge at Martinsville and a mile to the southwest, the deposits blocking the ancient valley east and northeast of Springfield Corners, and the dam blocking the valley at Lodi, where 194 feet of drift was penetrated by the well of the Chicago & North Western Railway. Of course, not all the drift within the limits of these morainal belts is referable to deposition at these stages of the glacial recession; part of it was deposited during the glacial advance and some may have been deposited at an earlier stage of glaciation. About 2½ miles west of Lodi one position of the ice margin can be distinctly traced across valleys and over ridges 100 to 200 feet in height by a very slight morainal ridge only a few rods in width. Small temporary glacial lakes bordered the ice front in several places and the waters escaped westward along the valleys by cutting through the earlier morainal deposits.

In the Wisconsin Valley between the hills of T. 10 N., R. 7 E. (West Point Township), on the south and the Baraboo quartzite range on the north morainal deposits are spread over a tract 6 miles wide from east to west. These are separated from the deposits of the Johnstown moraine by a marshy valley along which the waters escaped to a sag in the outer moraine. Wisconsin River was thus reestablished across the outer moraine and the bordering outwash terrace deposits and began at once to erode these. Morainal topography is well developed at several places, particularly between 1 and 2 miles northwest of Merrimac. A well in this part penetrated the following deposits:[1]

Log of G. W. Lee's well a mile northwest of Merrimac, Wis.

	Feet.
Clay, gravel streaks, and coarse sand	150
Hard clay with streaks of gravel and sand	
Sand	97
Gravel	
	247

The lower sand and gravel, at least, is probably an earlier Wisconsin or pre-Wisconsin glacio-fluviatile filling. (See pp. 244–245.)

The margin of the glacier across the Baraboo quartzite ranges at the Milton substage appears to have been considerably more direct than at the time of the maximum extension of the ice. From the top of the south bluff above Parfreys Glen a morainal deposit continues nearly due north across the trough to the north range east of the Lower Narrows. The moraine is most distinctly marked along Rowley Creek, in secs. 35 and 36, Greenfield Township. A part of the deposit also lies west of Baraboo River for a mile or more above the narrows. Morainal drift nearly surrounds Pine Bluff, and what appears to be its continuation is seen in a narrow ridge projecting into the big marsh from the lower north slope of the north range, a mile east of the narrows. F. B. Clarke, driller, Baraboo, reports that William Wyland's well in this morainal belt near the crest of the South Range,[2] about 5½ miles a little east of north from Merrimac, penetrated the following deposits:

Log of William Wyland's well in sec. 12, Greenfield Township, Sauk County, Wis.

	Feet.
Clay and sand	190
Muck and peat	?
Sand and fine gravel	44
Cambrian sandstone	6
	240

This shows two stages of filling in an old valley in the quartzite. It is not known that the lower sand and gravel are glacial, and the peat and muck overlying it seem to indicate that it was at least deposited prior to the last ice invasion. Part of the overlying drift belongs with the Milton morainal deposits.

The disappearance of the ice from the north and south ends of the Devils Lake Gorge caused a lowering of the lake to the level of the lowest point in the morainal crests. There is no indication that the water ever overflowed the south dam, whose lowest point is about 1,020 feet above sea level. As the ice in the Baraboo Valley melted glacial Lake Baraboo was extended eastward to the Milton moraine but continued confluent with glacial Lake Wisconsin. The cuts through the morainal deposits made by Rowley Creek, one of which is nearly 80 feet deep, must have been made since the draining of glacial Lakes Baraboo and Wisconsin as these waters must have entirely submerged the crests of the moraines where eroded.

North of the quartzite ranges the glacial front lay along the buried preglacial valley of Wisconsin River. South of the river two morainal tracts rise 100 to 160 feet above the surrounding marshes. North of the river the marginal deposits were built up into well-defined morainal ridges, 20 rods to 2 miles in width, which rise 20 to 120 feet above the extensive bordering marshes.

In southeastern Jackson and southwestern Oxford townships (T. 15 N., Rs. 7 and 8 E.) the two ridges coalesce with the outer or Johnstown moraine in a broad belt 6 to 7 miles in width, which for most of the next 20 miles northward into Waushara County is not very clearly divisible into its component parts. In the eastern half of New Chester Township a rather poorly defined east slope to the higher western part of the belt may differentiate it from the less strongly marked morainal tract to the east. For about 3 miles in T. 17 N., R. 7 E. (Lincoln Township), a nearly flat plain, resembling an outwash terrace, one-half to 1 mile in width, separates the broader eastern part of the belt from an outer moraine three-fourths mile wide. If the outer belt is the Johnstown moraine, that to the east would be grouped with the Milton moraine. About 8 miles farther north, in Waushara County, a similar but much more extensive separation of the outermost moraine from the moraines to the east

[1] Data from F. B. Clarke, driller Baraboo, Wis.

[2] The writer has some doubt about the correctnesso the location given for this well.

suggests that the outer ridge may really be an early Wisconsin moraine, corresponding to the Brooklyn moraine in Dane, Green, and Rock counties.

In T. 17 N., R. 8 E. (Springfield Township), several hills of sandstone rise above the surrounding morainal deposits. These hills have generally smoothly rounded contours and are notably lacking in towers and castellated forms such as characterized the sandstone bluffs outside the glaciated area. The broad morainal belt is marked by rather large swells and by many depressions, both large and small. From south to north, all through the central part of the township, the morainal topography is strongly marked. The soil of the moraine is sandy and considerable tracts are wooded. Adjacent parts of secs. 8, 16, 17, 20, and 21 have a nearly flat surface, resembling an outwash terrace pitted with many depressions.

The final stand of the ice before the opening of an outlet for the waters of glacial Lakes Wisconsin and Baraboo around the east end of the quartzite ranges appears to be marked by the morainal deposits 6 to 8 miles northeast of Merrimac on the north side of the river, by the morainal ridge cut through Rowley Creek, a mile east of the Sauk-Columbia county line, in the trough between the quartzite ranges, by a morainal deposit banked against the lower north slope of the north range 3 miles east of the Lower Narrows, and by the morainal island rising above the marshes between the Baraboo and Wisconsin rivers near the county line. North of the river in the southwestern part of T. 13 N., R. 7 E. (Lewiston Township), other small island ridges rise above the marsh just east of the main ridge. Farther north this position may be marked by the ridge in the western Douglas and southwestern Oxford townships (Tps. 14 and 15 N., R. 8 E.).

The margins of these morainal ridges between the Baraboo Bluffs and southern T. 15 N., R. 7 E. (Jackson Township), are fairly regular, and the slopes in many places are abrupt. This probably resulted from the drift being dropped in the waters of glacial Lake Wisconsin, which was extended eastward as the ice front retired. The crests of the ridges are below what must have been the level of submergence. As the morainal drift was deposited in standing water the ridges are nowhere bordered by outwash terraces, but on the lower slopes and in intervening lower areas is a deposit of dense reddish, calcareous clay similar to that (see pp. 226–230) in the basins of the glacial Lakes Wisconsin and Baraboo outside the Johnstown terminal moraine. The exposure of similar laminated red clay at several places in the tracts drained by Neenah Creek, in the northeastern part of Jackson Township, indicates that this part also was submerged by the lake waters. So far as the writer has been able to determine from records of wells on the moraines this clay does not extend under the ridges as it would if it were an earlier deposit but is confined to the intervening low areas. It must be admitted, however, that the data do not conclusively prove this. In Jackson Township where the two morainal ridges coalesce with the Johnstown moraine some wells do penetrate deposits of red clay below more or less sand. The coalescence of the moraines in this part, however, may mean that there was crowding forward of the ice following slight retreats such as would result in morainal drift being dumped upon the lacustrine clay, so that it is not clear that the clay at these places was deposited prior to the Wisconsin stage of glaciation. In places red clay is worked into the sandy drift in such a manner as might result from the ice crowding forward over the lacustrine deposits. Laminated red clay is exposed in places west of the Oxford mill pond; in a railway cut, the second west of this pond, visited by the writer in 1910, a bed of red, pebbly clay overlapped the east slope of a small ridge of sand as though the clay had been worked up into the morainal swell by push of the ice from the east.

Structure and composition.—The structure and composition of the Milton moraine is about the same as that of the Johnstown moraine. Most of the wells penetrate considerable deposits of sand and gravel, though south of the Baraboo Bluffs there is generally a sufficient coating of loamy clay to afford a good soil, where the surface is not too rough for cultivation. Many of the wells encounter more or less stony clay till, and many of the surface exposures show only unassorted material. A road cut 1¾ miles north of Milton exposes 25 feet of poorly assorted drift ranging from fine rock flour to bowlders 3 feet in diameter piled together in the greatest confusion. North of Wisconsin River the morainal ridges are composed of loose drift, for the most part so sandy that it is not easy to determine the depth to which weathering has extended. Where calcareous clay or sandy clay forms the surface leaching extends to depths of 1 to 4 feet, according to the density of the deposit, and the brownish tint due to oxidation extends to depths of 2 to 2½ feet. At a few of the exposures some of the crystalline pebbles are disintegrating, but these may have been derived from an earlier drift sheet.

The average thickness of the drift over 107 square miles of the Milton moraine south of the Baraboo Valley has been estimated at 67 feet. This includes all the unconsolidated deposits of Wisconsin or pre-Wisconsin age in this belt. The estimate is based on the depths of 48 wells which entered the rock beneath, on 46 wells which did not reach the rock, and on the topographic relations at 30 or 40 points where rock was exposed at the surface. North of Wisconsin River 33 wells on the morainal ridges penetrated an average of 83 feet of drift, but none of these reached the rock bottom of the buried Wisconsin River valley, so that the full thickness may be considerably greater. The average obtained from all the data is 70 feet of drift over an area of 130 square miles. North of Jackson and Oxford townships, over the 60 or more square miles of this moraine, little information was obtained concerning the wells. The average thickness in this part is probably fully as great as that cited above.

Analyses made by counting and sorting pebbles at 35 places distributed along the moraine from the interlobate angle southeast of Whitewater to Oxford Township, Marquette County, show something of the lithologic composition of the drift. Niagara dolomite decreases westward from 29½ per cent in Walworth and Rock counties to nothing in Milton Township. Pebbles from the Galena and Trenton predominate from the interlobate angle westward to the vicinity of Stoughton, ranging from 57½ to 90 per cent. Beyond this they are replaced by Lower Magnesian limestone pebbles, which constitute 80 to 90 per cent of the whole in the vicinity of Lodi but nearly disappear from the sandy drift in Oxford Township and farther north. Sandstone usually contributes more to the finer material of the drift than to the pebbles, yet a few sandstone pebbles are generally present, the highest percentage (20 to 21) being found in Fitchburg Township south of Madison. A few quartzite pebbles occur (1 to 8 per cent) principally between Rock River and Fitchburg, since this part of the moraine received contributions from the quartzite ledges exposed in the vicinity of Waterloo, 25 to 30 miles to the north. Along the west side of the lobe quartzite is nearly absent except in the immediate vicinity of the Baraboo Bluffs. Crystalline pebbles, which are almost the only undoubtedly foreign constituents of the drift of the moraine, range from 2 to 24.5 per cent, with an average of 10.86 per cent. North of the Baraboo Bluffs a part of the crystalline material is from the knobs of pre-Cambrian granite and porphyry exposed at Montello and in the towns of Marcellon, Buffalo, Moundville, and Marquette.

The tract between the Johnstown and Milton moraines is partly occupied by outwash deposits but between Rock River and Middleton by about 65 square miles of ground moraine. Rock outcrops at 59 places in this tract, but from the records of about 100 wells it is estimated that the drift has an average thickness of 43 feet—less than in the morainal belts on either side. North of the Black Earth Valley the moraines are less widely separated and the drift is generally thin.

The concentration of drift in the morainal belts indicates that the ice was not stagnant when the margin stood at the moraine but that it was bringing forward drift and depositing it as the ice melted about the margins.

OUTWASH SAND AND GRAVEL AND DRAINAGE CONDITIONS.

In general, less extensive deposits of outwash material are associated with the Elkhorn and Milton moraines than with the Johnstown and Darien moraines. Beyond the limits of these deposits the glacial waters accomplished considerable erosion.

Sugar Creek and Lagrange townships.—One of the most notable deposits of outwash material is that between the Darien and Elkhorn moraines in Tps. 3 and 4, R. 16 E. (Sugar Creek and Lagrange townships). As already stated (pp. 258–259) the junction of the fronts of the Delavan lobe and the Green Bay Glacier was removed to the vicinity of the village of Lagrange when the Elkhorn and Milton moraines were formed. This position allowed the gravel-bearing water from a frontage of 3 miles of the Green Bay Glacier to be discharged into the low area behind the Darien moraine, where it commingled with that from the Delavan lobe, and with that discharged from the trough formed by the contiguous frontal slopes of the two glaciers for many miles to the northeast. This outflow was unrestricted and vigorous, so that the area between the moraines received a filling of sand and gravel which extends as far south as the valley occupied by Sugar and Turtle creeks, 6 to 7 miles from the Milton moraine. As in the other outwash terraces the sand and gravel are generally coated with a few feet of clay and prairie loam. Except for two lightly elevated tracts of drift deposited by the Delavan lobe and surrounded by outwash material and for the depression occupied by Holden Lake, in which a great mass of ice must have lain, this plain is nearly flat, declining gently from the moraine toward the south. (See Pl. XXX, p. 258.)

The disposition of the deposit indicates that the outwash was principally from the Green Bay Glacier. The percentages of pebbles from the Niagara dolomite, as determined by the estimates at five different exposures, are intermediate between the low percentages of Niagara material in the Milton moraine and the high percentages of material from the same formation in the Elkhorn moraine, so that probably more or less mixing occurred.

Of 17 wells on this plain and the adjacent moraines concerning which information was obtained, 5 were reported as reaching rock at 200 to 235 feet. The following records show the character of the deposits penetrated:

Log of George McDougal's well at Heart Prairie, Wis.

	Feet.
Clay	3–5
Coarse gravel, about	70
Sand, about	125

Log of William Sherman's well near east end of Holden Lake, Wis.

	Feet.
Clay soil	2
Coarse gravel	45–50
Sand, about	50
Hardpan	20
Sand and gravel, about	100
	222

Two or three wells northeast of Heart Prairie penetrated about 130 feet, mostly "hardpan," probably till deposited by the Delavan lobe and buried by outwash. A certain amount of outwash borders the front of the Elkhorn moraine west of the city of Elkhorn, and a like deposit about 2 square miles in extent lies east of Delavan Lake. The waters from the south front of the Delavan lobe and from the ice in southwestern Racine County and western Kenosha County escaped by depressions through the earlier morainal deposits to the outlet through the outer moraine at Genoa Junction, now traversed by Nippersink Creek.

Plain between Milton and Johnstown moraines.—The interval between the Milton and the Johnstown moraines east of Rock River is occupied by an outwash plain a few rods to 2 miles in width. This is well developed in northwestern Richmond, southwestern Lima, and southern Milton townships. In the eastern tract the moraine and outwash are clearly distinct, the morainal crest rising 15 to 40 feet above the gently sloping terrace. Farther west the two are less distinct; in passing from the moraine to the outwash terrace the surface lowers and the depressions become less numerous until they almost disappear. The boundary line between the two is more or less arbitrarily drawn. In some places the outer and inner moraines are practically continuous.

Obstruction to the westward flow of the water accumulated between the Milton and Johnstown moraines in adjacent parts of Walworth and Rock counties caused an overflowing through narrow sags near Richmond. The water thus escaping reached Turtle Creek near Fairfield post office by the channel leading southward from Richmond through a cut in the outwash plain. A similar channel across the combined Darien and Johnstown morainal deposits between Whitewater and Holden lakes southwest of Heart Prairie allowed some of the water to escape to the low area east of the Darien moraine. As soon as there was free outlet across the morainal deposits to the west the waters from the eastern ice front flowed to Rock River, developing the broad channel about the hill south of Milton and the narrow channel leading thence to Rock River west of Milton Junction.

Fitchburg Township.—Waters from the northwest as far as the town of Fitchburg also discharged by the Rock River outlet, depositing the sand and gravel bordering the Badfish Creek marshes. In southeastern T. 6 N., R. 9 E. (Fitchburg Township), north of Oregon, a nearly inclosed body of water caused the deposition of lacustrine sediments. One well on the flat penetrated the following:

Log of A. O. Fox's well, a mile north of Oregon, Wis.[1]

	Feet.
Clay	5
Sand, about	70
Sand and blue clay in layers, about	60
Marsh muck with driftwood	?
Cambrian sandstone	?
	135

A similar deposit was made by the glacial waters beneath the flat traversed by the railway north of Fitchburg, the water escaping southeastward through sags in the outer moraine to the basin north of Oregon and thence to Badfish Creek. James Whelan's well on this flat east of the Lower Magnesian limestone hill and the railway penetrated 126 feet of filling, showing the presence of a buried valley.

Nine Springs Marsh.—A finely formed crescent moraine lying across the head of Nine Springs Marsh 2 miles south of Lake Wingra marks the position of a small lobe of the ice front in this valley after it had melted back about a mile from the front of the Milton moraine. This moraine is about one-fourth mile wide, has a relief of 50 to 60 feet on the west and of 100 to 120 feet on the east, and curves through an arc of 180°. Four wells on its slopes penetrated 85, 100, 150, and 178 feet of drift, showing the continuance beneath this morainal ridge of the valley containing Nine Springs Marsh. The small basin just west of the ridge must have been occupied by a lake and doubtless contains a deposit of lacustrine silt. A road cut in the ridge just west of the State fish hatchery exposed very stony, sandy, partly stratified drift and, in its lower western part, much fine, clean, white sand with bedding dipping gently to the basin on the west. After the disappearance of the ice the basin was drained about the north end of the ridge by Nine Springs Creek.

Verona Township.—The valley traversed by the Lancaster & Galena branch of the Chicago & Northwestern Railway between the Milton moraine and Verona was also an outlet for glacial waters. Tributary channels brought waters to this outlet from as far north as the divide 2½ miles southwest of Middleton near the top of the south slope of the Black Earth Valley, thus draining a glacial frontage of about 7 miles. It was this discharge which eroded the deep cut through the Johnstown moraine now occupied by Badger Mills Creek just south of Verona. A second similar narrow cut through the outer moraine in sec. 5, T. 6 N., R. 8 E. (Verona Township), about 3 miles northwest of the village, was probably developed by glacial waters ponded in the basin behind the ridge as the ice front retreated to and across the east rim of the basin. The outlet at this point is a narrow gorge about 60 feet in depth cut through the drift ridge and down to the rock forming the north slope of the buried preglacial valley.

The discharge from these two outlets joined Sugar River 2 miles southwest of Verona and eroded the gravel terrace which was formed when the ice front stood at the Johnstown moraine. The second terrace thus formed along Sugar River first becomes noticeable about a mile northwest of Paoli. Thence southward past Brodhead it forms a sandy alluvial flood plain a few rods to a mile in width and in many places marshy, through which the stream meanders. From this flood plain short, abrupt erosion slopes 5 to 20 feet in height rise to the broad sandy outwash plain formed by the glacial waters of the Johnstown substage. The upper terrace lowers near the State line in T. 1 N., R. 16 E. (Avon Township), where the two terraces merge in a broad marsh many square miles in extent.

Middleton Township.—When the ice front lay across the big rock hill in the midst of Black Earth Valley 3 miles west of Middleton the glacial waters cut an outlet through the outer moraine and eroded a channel in the outwash deposits that form the flat bottom of the valley westward to the Wisconsin. Near the glacial front a small terrace of gravels was formed. With the recession of the ice front to the next position a mile farther east the waters were ponded and discharged around the south side of the rock hill. The small lake basin at this place is now occupied by a marsh. At the third stand of the ice front this lake extended westward through a narrow sag in the moraine and received the outwash gravels that formed the terrace on the north side of the railway 1 to

[1] Data from B. D. Riley, driller, Oregon, Wis.

2 miles west of Middleton. At the fourth stand the glacial front was at the moraine extending southward from Pheasant Branch at the west end of Lake Mendota basin, and the waters expanded in a lake about 3 square miles in extent, covering the flat northwest of Middleton. To this temporary lake F. T. Thwaites, who has made a somewhat detailed study of the deposits, has given the name glacial Lake Middleton. The waters continued to discharge westward and washed into this basin much assorted drift material. Several wells on the moraine penetrate 80 to 201 feet principally of sandy drift, showing that a considerable valley underlies the ridge. This valley also continues westward beneath the lake flat. The moraine rises 60 to 80 feet above the marsh to the east, but from its crest a nearly flat terrace extends westward to a slight marginal slope which drops down to the lake flat. This margin of the terrace may be traced northward from the village a short distance east of the north-south road. The moraine, terrace, and lake beds are now cut by a ravine through which Pheasant Branch drains the basin to Lake Mendota. The sides of this ravine near the bridge north of Middleton expose 10 to 15 feet of clean white stratified sand, with cross-bedding dipping westward. According to W. J. Schneider, driller, Middleton, several wells on the lake flat penetrate 100 to 226 feet of drift.

Log of John Schroeder's well, three-fourths of a mile north of Middleton, Wis.

	Feet.
Sand	100
Peat	1
Clay	125
Cambrian sandstone	2
	228

Log of well at post office, Middleton, Wis.

	Feet.
Sand	60
Blue stony clay with wood at depth of 92 feet	73
Cambrian sandstone	2
	135

A well one block west of that at the post office encountered wood beneath 52 feet of sand and above 80 feet of drift. The well at the American House penetrated 60 feet of sand and 60 feet of underlying blue clay, probably glacial till. It is not known that all the sand was deposited in the lake; some of it may have been deposited in connection with the advance of the ice. Some of the wells penetrate 40 feet or so of clay, which may be lacustrine silt, above a thick deposit of sand. The peat penetrated by Mr. Schroeder's well may indicate an interval of exposure and vegetal growth which was pre-Wisconsin, so the 125 feet of clay underlying the peat may be a remnant of an earlier filling. The wood encountered in other wells may be evidence of similar conditions, or may have been brought with the drift and not have grown where it was found.

Roxbury Township.—Several valleys between the Black Earth and Wisconsin valleys were occupied by glacial waters while the Milton moraine was being formed, and some of them held small temporary glacial lakes, now transformed to marshy flats near Springfield Corners and Roxbury. In the valley 3⅓ miles northwest of Springfield Corners, in sec. 25, T. 9 N., R. 7 E. (Roxbury Township), a flat terrace declines westward from the middle moraine. Where this is cut by the creek 10 feet of finely laminated calcareous clay is exposed. There was evidently a small basin which was silted up behind the moraine next to the west.

Wisconsin Valley.—A succession of small temporary glacial lakes occupied the Wisconsin Valley along the Columbia-Dane county line between Sauk City and Lodi as the ice front retired to the successive positions of halt marked by the morainal deposits. Fish and Crystal lakes occupy depressions resulting from the melting of buried ice blocks. West of Fish Lake a flat terrace leads to the head of a narrow outlet which was cut through the Johnstown moraine and was left hanging 100 feet or more above the Wisconsin by the later deepening of the river channel.

The marshy valley 2 miles west of Merrimac now occupied by the creek heading in Parfreys Glen was the channel of the headwaters of Wisconsin River when the glacial front stood at the western part of the Milton moraine. The glacial waters crossed the Johnstown moraine at the lowest sag, and the stream, which had been depositing sands and gravels washed out from the outer moraine, began eroding this moraine and bordering terrace. A channel through the moraine 2½ miles north of Prairie du Sac was occupied by a stream which flowed westward across the the terrace and then southward near the foot of the sandstone bluffs in the channel now occupied by Otter Creek. Near Prairie du Sac the main stream was cutting and shifting its course, and possibly it at this time developed the second terrace, on which Prairie du Sac and Sauk City now stand. The abrupt eroded slope rising from this terrace to the original plain is well developed just west of Prairie du Sac, whence it extends southwestward toward Lodi mill. As the ice front retreated the glacial stream was extended eastward across the moraine to the broad unfilled tract east of Merrimac now occupied by Wisconsin River and Rowan and Prentice creeks and the bordering marshes. The bluish stratified clay exposed in a gully beside the road one-half mile southwest of Alloa Church was probably deposited in a small lake.

Glacial Lake Baraboo.—As the ice in the Baraboo Valley melted glacial Lake Baraboo was extended eastward to the Milton moraine and with the opening of the Lower Narrows Gorge it became confluent, at this place, with the lake north of the north range. The water must also have extended through the sag in the north range 2½ miles west of the Lower Narrows, leaving a large island between the two straits. As the outlet of the confluent lakes was not changed from that near Mather, Wis., however, the level of the bodies of water continued the same as before, except for such lowering as was due to their union. The moraine crest west of Baraboo must thus have been nearly submerged or have appeared as a low bar extending partly across the lake. None of the hills in the basin south and east of Baraboo would have been above water. The average thickness of drift penetrated by 9 wells in the part of the basin between the Johnstown moraine and the Lower Narrows is 121 feet, but it is not known that any of this is to be referred to deposition in the lake after the ice front had retreated. The bed of buff loesslike clay overlying stratified sand and gravel at the gravel pits in the northeastern part of Baraboo may be silt deposited at the north shore when the lake was thus extended, but it looks more like wind-blown dust.

Glacial Lake Wisconsin.—As the ice front north of the Baraboo Bluffs withdrew from the Johnstown moraine to the successive ridges of the Milton moraine, water was ponded over the intervening lowlands and probably also overtopped the inner morainal ridges, as the only outlet was to glacial Lake Wisconsin, and thence by the col near Mather, Wis., to the Black River valley. The water probably still stood high enough to overtop the crest of the Johnstown moraine in places east of Delton, though to the north and south the two bodies of water were separated by the moraine and the higher parts of the bordering terrace. The body of water east of this moraine may thus be considered a part of glacial Lake Wisconsin.

The reddish calcareous clay, which occurs in the lowlands between the ridges of the Milton moraine (p. 262), is exposed at several places. It appears in a road cut just north of the big springs a mile northwest of the village of Big Springs. In another road cut a mile north and 1¼ miles east of the same village 18 feet of dense laminated calcareous red clay is exposed near the creek. In other places the clay is not clearly laminated but contains few or no pebbles. Laminated red clay is also exposed at numerous places in the Neenah Creek valley, northwest of Oxford.

Many wells penetrate considerable thicknesses of this clay, which in places is overlain by a thin bed of sand and underlain by sand or sand and gravel. In places a second bed of clay is penetrated between this sand and gravel and a lower bed of the same. The clay is said to range in thickness from 1 foot to 100 feet or more.

Near Big Springs the red clay covers an area of 3 or 4 square miles above the level of the marshes. Here the surface is gently undulating, like that of ground moraine. It is from beneath this clay that the fine artesian flows are obtained in the vicinity of Big Springs. The clay occurs beneath a thin covering of sand on the lower and gentler slopes bordering the steeper slopes of the sandy moraines and extends thence beneath the marshes.

From the relations it appears that considerable of this reddish silt was deposited in the deeper waters while the several morainal ridges were being built up in the waters close to the ice front. The underlying sands and clays were probably deposited during the advance of the Wisconsin glacier and possibly in part at an earlier stage.

TURTLE CREEK OUTLET.

From the time of the abandonment of the Darien moraine to the opening of the Sugar

Creek valley northeast of Elkhorn the valley of Turtle Creek through the Darien moraine west of Delavan was a very important outlet for glacial waters. For a time it carried all the water from the melting ice and from precipitation on the frontal slope of Delavan lobe from the valley of Jackson Creek on the south to the southwestern part of Waukesha County, a frontage of nearly 20 miles. When the Elkhorn moraine was abandoned a part of this flow was diverted to the southward, to the Nippersink outlet at Genoa Junction. In addition to the frontage on the Delavan lobe the part of the Green Bay glacial front north of the vicinity of Bass Lake sent its waters across the outwash plain to join the flow through this outlet. The interlobate drainage from the two glaciers for an undetermined distance to the northeast also made a large contribution to the flow until the Green Bay front withdrew from the Kettle interlobate moraine. It is also possible that for a time even after the withdrawal a certain amount of water from the Green Bay Glacier, ponded between the ice front and the moraine, found egress across the morainal crest through some of the numerous sags, and joined the flow to the Turtle outlet.

The location of the Turtle outlet west of Delavan was probably due to a sag in the crest of the moraine which was deepened and widened by the discharge until a valley varying in width from one-half mile to 1½ miles was developed. Kettle holes occur at one point in the north slope of the valley within 40 or 50 feet of the bottom, showing that not all the slope is due to erosion.

After passing the Darien moraine the waters found their way across the bordering gravel terrace to the valley in southern Bradford Township (T. 2 N., R. 14 E.), by means of which they crossed the area of the older drift and joined Rock River. For about 2 miles, where Turtle Creek traverses the area of the pre-Wisconsin drift, the valley is constricted, the stream being bordered by a flood plain only 20 to 40 rods in width, from which the slopes rise to heights of 80 to 100 feet, the lower 60 or 70 feet of which is cut in Galena dolomite. On the north side the rock is exposed in a vertical bluff but on the south side is less abrupt. At the east and west of this gorge the Galena is overlain by gravels of the outwash terrace, formed when the ice front stood at the Darien moraine. At the east end, these reach a level 60 to 65 feet above the present stream. It is probable that this rock gorge marks the position of a col in the rock ridge, at the head of the broad valley which opened to the west, and that this col was filled with gravels up to the level of the higher terrace. The vigorous outflow after the ice front melted back from the Darien moraine excavated much of these gravels, and subsequent erosion brought the valley bottom to its present position.

East of the head of this gorge three distinct stages may be traced in the development of the topography. At the first, the upper or main gravel terrace was formed, as already described (pp. 238–239), while the ice front stood at the Darien moraine. North of Turtle Creek this terrace has been but little modified by subsequent erosion, but south of the creek, to the border of the older drift area, only remnants of it remain. One of these, a terrace varying in width from one-half to 1 mile, borders the morainal front. The distribution of other remnants is shown on the map. Except for these remnants, over an area of nearly 8 square miles the relations seem to indicate that gravels were removed to depths of 20 to 50 feet, forming a gently undulating plain below the level of the upper terrace north of the creek.

The lower terrace continues eastward as the bottom of the Turtle outlet through the Darien moraine. This terrace, which is now cut by the meandering course of Turtle Creek, reaches an elevation 40 feet above the neighboring flood plain of the creek north of Delavan, a rise of 60 to 70 feet in 8 or 9 miles. This is not, however, a uniform gradual slope. It appears to have been developed by a current which shifted its course as the valley deepened. The incoming of the vigorous flow from the north, behind the Darien moraine, crowded the eroding current against the south side of the valley near Delavan, whence it was deflected sharply to the northwest and then to the southwest. The continued deflections in gradually shifting courses appear to have been the cause of the remarkably extensive erosion in the area west of the Darien morainal front.

For such extensive meandering as the conditions observed seem to imply some cause such as a retarding barrier below would seem to be necessary. The reported presence of 18 feet of filling in the bottom of the rock gorge, as shown by the piling at the bridge north of Clinton Junction, led the writer to infer[1] that the gorge must have been cut prior to the Wisconsin stage and not entirely reexcavated. The reported presence of this filling was not, however, verified, and if true it may possibly be due to subsequent deposition. If the gorge was not entirely excavated prior to the Elkhorn substage the limestone sill would furnish a barrier adequate to cause a large amount of meandering in the area to the east. Possibly a filling of compact drift left by the Illinoian glacier may have blocked the gorge so securely as not to have been reexcavated prior to the Elkhorn substage.

As the valley north of Delavan deepened, the outflow from the Elkhorn moraine directly to the east deepened its course, so that, instead of a continuance of the lower terrace from the east side of the Darien moraine to the front of the Elkhorn moraine, we find a broad valley heading farther north in a break in the slight outer belt of this moraine through which the waters of the main moraine found egress. The waters continued to come to this outlet from the north for a considerable time after the final abandonment of the Elkhorn moraine, until the opening of the Sugar Creek valley northeast of Elkhorn afforded a new and lower outlet. The flow gradually established itself in the broadly sinuous course of the present stream and developed a broad channel whose banks rise 10 to 40 feet to the variable surface of this second terrace.

Before the Turtle outlet was fully opened more or less discharge from the Delavan lobe seems to have escaped through a narrow break in the crest of the Darien moraine southeast of Richmond and to have been joined by a flow from the Green Bay Glacier which escaped through two narrow sags near the same village. The stream formed by the confluence of these outflows flowed southward on the outwash terrace near the front of the Darien moraine, where it eroded a channel 40 to 80 rods wide and 20 feet deep. In northeastern Darien Township this channel swings westward away from the moraine, then turns southward and reaches the Turtle Valley east of Fairfield.

KETTLE INTERLOBATE MORAINE.

The part of the Kettle interlobate moraine particularly associated with the Elkhorn and Milton moraines extends as a bold line of bluffs continuously for about 15 miles northeast from the junction of the two moraines south of Palmyra to the vicinity of Wales. To speak of this moraine as a bold line of bluffs is correct, for its northwest face rises abruptly from low marshes and borders on nearly flat tracts. This was an ice-contact face, and its original relief appears not to have been very considerably reduced by later deposits on the lowlands. The east side, however, as noted above, is bordered by extensive deposits of gravel, which, near the moraine, fill the area abandoned by the melting of the Lake Michigan glacier to 100 feet or more above the level of the lowlands on the west.

In Eagle Township and southern Ottawa Township the moraine, which here has a breadth of one-half to 1 mile, lies partly close to and partly upon the crest of the Niagara escarpment. The combined relief of the escarpment and the moraine is 100 to 200 feet, of which about 100 feet is due to the morainal deposits. On the west is a low, marshy flat, probably underlain by "Cincinnati" shale. On the east the surface drops down 20 to 40 feet from the crest to an outwash terrace.

Farther north, in the town of Ottawa, the Green Bay Glacier overrode the Niagara escarpment and pushed eastward 1 to 2½ miles. Here the west front of the moraine has a relief of 80 to 140 feet. In the southern part of Ottawa Township the outwash terrace becomes rougher and with the narrow moraine merges into a broad morainic tract over 3 miles in width. Four miles farther north the whole belt narrows to a mile.

The topography of the Kettle interlobate moraine is one of the unique features of this area. This has been described in numerous papers, particularly in several by Chamberlin. (See bibliography, pp. 21–24.) Its surface is marked by a knob-and-kettle topography which varies greatly in detail from place to place. At one place a series of gravel ridges not unlike railroad embankments may lie nearly parallel to each other and to the trend of the moraine. Traced for a short distance these ridges may become winding, inclosing deep irregular depressions with side slopes in places as steep as 30° to 35°, or they may break into more or less distinct conical knobs, irregularly distributed and interset with equally

[1] U. S. Geol. Survey Prof. Paper 34, pp. 48–49, 1904.

abrupt round or irregular depressions. Differences in elevation of 20 to 100 feet occur within the space of a few rods. The close and irregular distribution of these features and the abrupt changes in height of the knobs and ridges and the depths of the hollows form a labyrinth. On the one hand such an area may be flanked by a high, flat-topped, table-like ridge; on the other the reliefs may become less and the surface soften to one of gentle sags and swells or may give place to small inclosed basins, 20 to 200 acres in extent where the surface is gently undulating or nearly flat, affording tillable fields. The reliefs in general decrease from west to east, and the topography commonly changes gradually from the moraine type to that of the bordering outwash terrace.

The moraine, as shown by numerous exposures and by the records of wells within the morainic belt, is composed very largely of coarse gravel. A 50-foot section afforded by the road cut through the morainal crest a mile southeast of Palmyra shows pebbles, mostly well rounded, from a fraction of an inch to 8 inches in diameter. In the upper part of the section the gravels are stratified; lower down the structure was obscured at the time of the writer's visit. The stratified gravels run laterally into very stony till.

A partial exposure of this morainal material is afforded by the gravel pit of the Chicago, Milwaukee & St. Paul Railway, about a mile west of Eagle. The section here at the time of the writer's visit was one-eighth mile long and 25 to 30 feet deep. The stones, which range from fine gravel to blocks 2 feet in diameter, are generally well rounded and show no glacial striations. The material is loose and slides readily in the section, obscuring any assortment and stratification that may exist.

A second good exposure is afforded by the gravel pit of the Chicago & Northwestern Railway just west of the village of Wales. The upper 20 feet of the 30 to 40 foot section is of coarse gravel, below which is very stony till. Many large bowlders are scattered through the section. The bedding of the gravels dips gently toward the east—that is, away from the front of the Green Bay Glacier.

The high percentage of Niagara dolomite at the exposures just west of the margin of that formation indicates a considerable mixing of drift of eastern and western derivation. Not improbably much of this Niagara material was carried farther west during the earlier invasions.

The average of three estimates of the lithologic composition of the interlobate moraine gravels in T. 5 N., R. 17 E., and T. 6 N., R. 18 E. (Eagle and Genesee townships), show the presence of 18.6 per cent of foreign pebbles—somewhat more than that shown by most estimates of the drift of the Green Bay Glacier. Most of the pebbles are of crystalline rock from Canada, but a few are of quartzite from the Lake Superior region. The greater part of the material, 81.4 per cent, is limestone, mostly from the Niagara formation. Some years ago in digging a well on the moraine near Eagle a 15-karat diamond was found. This is one of the rarest constituents of the drift and was probably brought from Canada. (See pp. 221, 259, 301, and 308.)

SUBORDINATE MORAINIC DEPOSITS PERHAPS REFERABLE TO THE MILTON MORAINE.

Distribution.—Within the curve of the Milton morainal belt a line of somewhat widely separated morainal patches represents perhaps the last of the deposits which should be correlated with the Milton moraine, One of these is the deposit of drift on which the village of Lodi is built and by which the valley of Spring Creek was dammed until cut through by the stream. The Chicago & Northwestern Railway well on the lower part of this deposit near the railway bridge penetrated 194 feet of drift before reaching the rock bottom of the ancient valley. With these also should probably be grouped the patch of morainal deposits 1 to 2 miles southwest of Dane and that 1 to 2 miles east of Springfield Corners. The place where a stream discharged at the ice front when it stood at this position is shown by a narrow esker ridge of stratified gravels which borders the north side of the big marsh for 1¼ miles and merges with the morainal deposit. Another patch of about 2 square miles borders the northwest shore of Lake Mendota. Wells here penetrate drift of all thicknesses up to 60 feet.

Madison and vicinity.—The most interesting of these deposits occur in the vicinity of Madison and merit somewhat detailed description. Curving about the marsh at the head of University Bay is a finely developed crescent moraine marking the position of a small lobe of the ice front which lay in the ancient valley now occupied by the bay and marsh. This moraine is very similar to that at the head of Nine Springs Marsh 4 miles farther south. (See p. 265.) It curves through an arc of 180°, has a width of one-fourth to one-half mile, and a relief of about 60 feet on the west and 80 feet above the marsh on the east. A gravel pit near the railway gave a good exposure of the structure of the upper part of the ridge (at the time of the writer's visit). The lower part of the section showed finely interlaminated sand and clay in beds 4 to 6 inches thick, alternating with beds of sand which include a little clay in rippled wavy lines as though deposited in shallow water. Above 5 to 10 feet of gravel composed of pebbles, mostly 1 to 6 inches in diameter, formed the crest of the ridge.

L. Post's well on the west slope of this ridge is reported by Mr. William Haak, jr., well driller, to have penetrated 240 feet of drift before reaching sandstone. Another report gives the thickness of drift here as 253 feet. The remarkable gorgelike character of the buried valley is apparent from the fact that limestone is exposed in the railway cut barely 40 rods south of this well, and that a little farther south a hill of Madison sandstone capped with Lower Magnesian limestone (in which is located David Stephen's quarry) rises fully 60 feet higher than the curb of the well. On the opposite side, less than one-half mile north of the last-named hill, at Mendota Heights, a bluff of limestone and sandstone rises 120 feet above the intervening basin, or 100 feet above the curb of Mr. Post's well. At the bottom of this well, it is said, wood was encountered. That a temporary glacial lake occupied the head of the valley to the west during the formation of the moraine is shown by the presence of laminated silts at David Stephen's brickyard. The section exposed by the clay pit at the time of the writer's visit was as follows:

Brick clays, David Stephen's brickyard, Madison, Wis.

	Feet.
Black soil	½
Dense, stoneless gray clay, noncalcareous, with films of carbonaceous matter	5½
Finely stratified buff sand and sandy clay	5–12
Brownish gravel at west side of the pit	1–3
Dense, fine-grained calcareous clay; reddish brown above, grading downward to bluish, stoneless; breaks in little blocks coated with thin black or brownish films	15
Stony bluish clay, glacial till.	

If the ice front extended northward directly across the Mendota basin to the morainal deposit north of Fox Bluff, as is suggested by the configuration of the lake bottom shown by the submerged contours, a lake, the predecessor of Lake Mendota, must have occupied the west end of the basin and have discharged by the way of Pleasant Branch (reversed) to the outlet west of Middleton.

In a paper presented before the Geological Society of America at the Boston meeting, December 29, 1893, Upham discussed certain peculiar hills at Madison which he designated the Madison type of drumlins.[1]

These hills were Capitol Hill, Langdon Street Hill, University Hill, and Observatory Hill. Langdon Street Hill is probably a drumlin, but Capitol, University, and Observatory hills are not regarded by the writer as such. These latter hills have not good drumlin forms, and the last two have not an axial trend parallel to the direction of the ice movement as shown by numerous glacial striæ in the vicinity and by the orientation of neighboring drumlins. University and Observatory hills, together with the hill next southwest, known as University Heights, are regarded by the writer as morainal and to be correlated with the crescent moraine at the head of University Bay and with the moraine which is continuous from University Heights southeastward through the part of Madison known as Wingra Park and the narrow morainal ridge between Lakes Monona and Wingra.

The following borings on and near Observatory Hill show its structure: University farm, west of hill, drift 25 to 30 feet, limestone; dairy building, drift, mostly sand, 100 feet (authority, M. Whitson); horticultural building, drift 120 feet, sandstone 20 feet (authority, F. T. Thwaites); Washburn Observatory, drift, principally blue clay, 160 feet (authority, G. C. Comstock).

Upham describes superficial exposures and deposits penetrated by other wells on University Hill as follows:[1]

An excellent section to a depth of about 10 feet and 500 feet long, crossing the eastern slope of University Hill about midway between its foot and top, was supplied in 1892 by the trench for laying a large steam pipe from the boiler house to the new Law Building. At each end this

[1] Upham, Warren, The Madison type of drumlins: Am. Geologist, vol. 14, pp. 69-83, 1894.

trench found the till to reach from the surface to a depth of 5 to 8 feet, being underlain by sand. Thence the till gradually diminishes in thickness toward the central part of the section, where for a distance of some 200 feet or more the sand rises quite to the surface. This portion of the central sand mass, destitute of its usual covering of till, forms a slightly protuberant swell, 1 to 5 feet in height above the general slope, from close to the base upward for two-thirds of the height of the hill.

An excavation for a cesspool at the top of this hill close to Prof. Comstock's house, reaching a depth of 21 feet, found the bowlder clay 7 feet thick, and all its lower portion was in sand and gravel, the coarsest layers containing pebbles up to 6 inches in diameter. Here and there a few bowlders, up to 2 feet in diameter, were encountered in the stratified drift. Three to six rods southwest of the observatory an excavation in the southern slope to a depth of 20 or 30 feet was worked many years ago to supply sand and gravel for masons' use and road repairing. Much gravel and many bowlders of small and large size are embedded in the superficial till of this hill, as seen by me on its surface and in excavations to the depth of 10 feet for the foundations of the Agricultural College greenhouse, near the dairy house on its western slope. On the very top, only about 4 rods west of the observatory, a bowlder of Archæan gneiss, 10 feet long, lies half or more embedded in the till. Prof. R. D. Irving stated the depth of the drift under the top of this hill to the bedrock to be 122 feet.[1] Under its western part, at the dairy house, according to Prof. F. H. King, a well 48 feet above Lake Mendota went 6 feet in till, and all its remaining depth, to a total of 84 feet, in sand and gravel, not reaching the bedrock.

Concerning the deposit described above Chamberlin[2] writes as follows:

I do not think Upham's designation of the thin upper formation on University Hill, at Madison, as till should be quoted and passed without some qualification. It impressed me, as I saw it at various stages and in different excavations, as being a peculiar superficial deposit, probably due to the accumulation of englacial, chiefly foreign, crystalline bowlders at the surface of the ice near its terminus, by sublation, with which there was commingled eolian matter driven on the ice from the adjacent relatively bare territory, this being caught by dust wells and similar means. All this being melted and dropped together, constituted a till-like mixture, but something really very different from till. I saw something of the kind in process of formation in Greenland. Prof. Salisbury's interpretation, when he was at Madison, was the same. Now this, of course, involves a modification of the picture of the situation when this was put down upon the sands and gravels, but the process is less exacting than the supposition that it is true basal till driven up over the rather steep-sided hills of sand and gravel.

A well at C. E. Buell's near the top of one of the hills at University Heights is reported to have penetrated drift 108 feet, sandstone 42 feet. These hills stand on a broad rock ridge between two filled valleys, one on the north and one on the south, and were probably formed in a reentrant angle between small lobes of the ice front occupying these valleys.

The sharp narrow drift ridge between Lakes Monona and Wingra, described as an esker in the article quoted above, appears to the writer to be unquestionably a marginal moraine deposited in the waters of a temporary glacial lake occupying the Lake Wingra basin and held up by the ice front on the east. When seen by the present writer William Keyes's gravel pit exposed 30 to 35 feet of beautifully stratified sand and fine gravel, with bedding and cross-bedding dipping westward and southwestward into the Wingra basin. At the east side 1 to 5 feet of nearly stoneless buff clay overlay the gravels. The crest of the ridge rises 30 to 70 feet above the marsh on the west. The abruptness of the east slope of the ridge is due to its being an ice-contact face, and that of the west slope is due to the drift being washed into standing water and being precipitated immediately adjacent to the ice front. The waters being ponded, no bordering outwash terrace resulted. Lake Wingra and the bordering marshes are probably underlain by considerable amounts of lacustrine clays.

The continuation of this moraine as mapped by F. T. Thwaites is represented by a discontinuous line of gravel deposits extending southeastward nearly to Lake Kegonsa. A branch of the moraine formed when the ice front had contracted within the Lake Monona basin curves eastward and then southeastward along the lake shore through South Madison and the grounds of Monona Assembly. Nine wells on this branch are reported as penetrating 35 to 130 feet of drift, although rock is exposed on the south shore of the lake and on the Fair Grounds not far distant. This indicates considerable marginal deposition while the glacier lay in the basins now occupied by the lakes.

Just south of Nine Springs Marsh, in the northeastern part of T. 6 N., R. 9 E. (Fitchburg Township), the head of a drumlin is buried beneath some of these morainal deposits. The village of Stoughton is built partly on a small gravel terrace and partly on slopes developed by the erosion of this terrace. This terrace is best developed east of the river, where it rises northward to a narrow morainal crest which was probably formed about the time of the morainal deposits under discussion.

[1] Geology of Wisconsin, vol. 2, p. 625, 1877.
[2] Personal communication, June 28, 1913.

Lake Koshkonong basin.—The ice front must have been melted back to the basins of the four lakes and Lake Koshkonong about the same time. Its position between Lake Kegonsa and Lake Koshkonong is not clearly shown. Possibly it may have extended nearly eastward to the valley south of Rockville and thence southward as a lobe in the preglacial valley of Rock River. This seems probable from the occurrence of a well-marked belt of morainal topography from the vicinity of Ripley Lake to the Milton moraine east of Edgerton. The character of this belt, however, is not such as to show clearly its relation to the ice front; and, indeed, it is probable that the ice front may have shifted its position gradually while the deposit was being formed. Large depressions northwest of the west end of Lake Koshkonong indicate the burial of considerable masses of ice. One position of the margin is shown by a small ridge strewn with abundant bowlders, which extends northwestward through sec. 13, T. 5 N., R. 12 E. (Albion Township), to a very strongly marked kame and kettle tract north and northeast of Rice Lake. From this position the ice front appears to have extended backward toward the north and east so as to open a basin behind this morainal deposit while still blocking the valley on the east near the Dane-Rock county line. On the north and east are morainal deposits with kame and kettle topography, and the basin is underlain by outwash sand and gravel and lacustrine clay. The deposits overlie indiscriminately large rock ridges and intervening buried valleys, so that the thickness of drift in this belt varies from nothing to more than 200 feet.

In this connection it may be noted that the rock floor of D. Pierce's cellar at a point near the east margin of this belt a mile northwest of Sumner shows glacial striæ bearing S. 49°–64° W. Striæ observed near the crest of the ridge in the SE. ¼ sec. 27, T. 6. N., R. 13 E. (Oakland Township), trend S. 38° W. The trend of these striæ is more southwesterly than that of the general advance of the ice east of this belt and may have been the result of lobation of the ice margin at the stage shown by the morainal deposits under discussion. These striæ may, however, have been graven by an earlier ice advance.

While the ice front lay in the Koshkonong basin the glacial waters escaping to Rock River extended that stream in a sag across the Milton moraine. The extensions of this stream during the formation of the Milton moraine and at this time carried the head of the stream from the line of the preglacial Yaharah Valley across two buried rock ridges and an intervening filled valley to the preglacial valley of Rock River, in which is Lake Koshkonong. In consequence of this location the stream, on cutting through the drift, was forced to cut a channel through the crests of these buried ridges between Fulton Center and the lake. (See Pls. I and II, in pocket.) The cutting of the rock channels has greatly retarded the drainage of the large part of the stream's basin which lies within the terminal moraines.

At this stage the deposition of the morainal drift north and east of Otter Creek in the vicinity of Koshkonong station and the lake was completed. In the towns of Lima and Whitewater (T. 4 N., Rs. 14 and 15 E.) a discontinuous line of meager morainal deposits, nowhere more than 1½ miles distant from the inner border of the Milton moraine, shows the position of the ice front. In northwestern Lagrange and southern Palmyra townships (Tps. 4 and 5 N., R. 16 E.) the deposits become continuous and border the foot of the line of bluffs which form the northwest front of the Kettle interlobate moraine. These deposits indicate that the ice front had just begun to withdraw from this moraine as far northeast as Palmyra. Beyond this point, as shown by the conditions on the east side, the front of the Green Bay Glacier continued pressed snugly against the Kettle moraine, so that an extensive terrace was formed by the washing of gravels across the moraine and into the area that was being abandoned by the melting of the Delavan lobe.

It is, of course, not to be supposed that really accurate detailed correlation of such slight and widely separated patches of morainal deposits can be made. When these are all mapped, however, and considered in their relations to the other moraines they may be grouped with some considerable degree of probability into belts representing successive positions of the ice margin, although the particular relations of each small patch may not be evident either in the field or on the map.

Northeast of Whitewater are two irregular elevated tracts pitted in places with kettle holes. With these are correlated the sandy ridge extending thence northwestward to Cold Spring, the morainal hill on which stands the schoolhouse in the south part of Fort Atkinson, and the hills southwest of the stone quarries in adjacent parts of secs. 9, 10, 15, and 16, T. 5 N., R. 14 E. The thickness (200 to 275 feet) of drift penetrated by wells in Fort Atkinson, within 1½ miles of the stone quarries, shows that a great valley is buried beneath the glacial deposits.

Palmyra Township.—Wells distributed along the roads across the low tract traversed by the railway southwest of Palmyra penetrate 25 to 234 feet of drift, showing that a considerable preglacial valley is buried there. Part of this filling may be morainal. Extending somewhat east of north from the vicinity of Palmyra is a bulky ridge of drift, which appears to be a moraine, or at least to have received more or less of morainal deposits. For a mile or two east and northeast of Palmyra are gravel knolls, sand-coated hills, and kettle holes. Thence northeastward into western Ottawa Township (T. 6 N., R. 17 E.) the ridge averages 2 miles in width, with a relief of 120 to 160 feet above the Scuppernong Marsh on the west.

The surface of the main ridge is undulating, in some parts very gently, in others rather sharply; in some places it is marked by kames and kettle holes. The ridge is well sprinkled with bowlders, mostly crystallines, which are very abundant in some places. The soil, in places, is sandy, though it is generally clay. Cuts expose gravel and very stony till. Numerous wells on this ridge have penetrated 120 to 160 feet of drift without reaching rock. The east front of the ridge is bordered in part by an outwash deposit of sand and gravel in parts of the towns of Palmyra, Eagle, and Ottawa.

Summit Township.—Between 3 and 4 miles southwest of Dousman the bulky ridge gives place to a complex of marshy tracts, outwash terraces, and slight moraines or ice-contact slopes, indicating positions of the ice front. Just east of Dousman the ice margin at one time extended over the buried escarpment of Niagara dolomite south of the Chicago & Northwestern Railway; here there is an abrupt pitted slope and morainal crest with a relief of about 80 feet on the north. From this crest a somewhat pitted and uneven terrace of morainal and outwash gravels declines to the marshy depressions on the south. Beyond the valley of Scuppernong Creek the moraine runs nearly due north to the vicinity of Delafield, lying but a short distance west of the abrupt west slope of Government Hill, a part of the interlobate moraine.

Oconomowoc Lake region.—A second position of the ice front lay entirely west of the buried Niagara escarpment from Dousman to Delafield, where it joined a broad morainal tract extending northward between Lake Nagawicka and Lakes Nashotah and Nemabin. This position is indicated by a short westward slope or a slight ridge sprinkled with bowlders, marking the ice-contact margin of the pitted gravel terrace extending from Lower Nemabin Lake southward to the railway.

A third position is represented by the chain of depressions occupied by Genesee, Otis, Duck, Egg, Crooked, Upper and Lower Nemabin, and Lower Nashotah lakes, which through most of its extent is flanked on both sides by pitted terraces. Wells on one of these terraces at Dousman penetrated 110 to 120 feet of drift, mostly sand. North of Waterville the deposits thin as the dolomite rises to the surface.

E. L. Thomas's well, on the morainal ridge 1¾ miles south of Delafield, penetrated 100 feet of drift to rock. Mr. Davis's well, on a slope of the moraine one-half mile west of Delafield, passed through 230 feet of drift as follows:

Partial log of Joseph Davis's well, one-half mile west of Delafield, Wis.[1]

	Feet.
Glacial till	36
Sand	
Gravel	4
Hardpan	160
Red clay	28
Gravel	2
"Cincinnati" shale	121
Hard rock (limestone)	15
	366

This undoubtedly includes earlier Wisconsin and pre-Wisconsin deposits. The shale encountered is thought to form part of the southeast slope of the ancient buried valley of Rock River.

The wonderful beauty of this Oconomowoc Lake region and its popularity as a summer resort are due to the combination of glacial mo-

[1] Information from Charles Butler, well driller, Delafield, Wis.

rainal ridges, broad flat terraces, and abundant lakes, principally the latter. These lakes are the result of the burial of great masses of glacial ice in the drift filling this ancient valley; the subsequent melting of the ice allowed the overlying drift to settle, forming the depressions now occupied by the lakes and ponds. The basins in this belt of deposits vary in depth from 20 to 70 feet or more. Nagawicka Lake has a depth of 94 feet.

INTERLOBATE ANGLE.

Topography.—Northeastward from the vicinity of Palmyra the Green Bay Glacier appears to have continued crowded against the west face of the interlobate moraine for some time after the ice on the east had begun to melt away. This moraine is bordered on the east by an extensive terrace of outwash gravels, but its northwest face is abrupt and high, and the tract to the west is low and not filled like that to the east. A remnant of the terrace extends northward to the north line of T. 5 N., R. 17 E. (Eagle Township). On the south it terminates at the valley of Sugar Creek, the gravels having filled in behind the Elkhorn moraine as the Delavan glacial lobe melted away.[1]

From Lauderdale lakes to the village of Mukwonago the surface of the drift is pitted by a remarkable series of depressions, the result of the burial of the marginal parts of the disintegrating glacier by morainal and outwash deposits. The character of the topography thus produced is shown on the Eagle and Whitewater topographic maps.

The largest and most notable of the depressions is the very irregular branching valley, 10 miles in length, in which lie Lake Beulah, East Troy, Phantom, Eagle, and Lulu lakes, and an extensive marsh. That these larger depressions are essentially connected series of kettle holes and are not due to fluvial erosion is shown by their exceedingly abrupt and irregular marginal slopes and by the inequalities in depth where not now occupied by marsh deposits. Many of the lakelets, ponds, and marshes occupying these depressions lie 50 to 80 feet below the surrounding plain. The marginal gravel slopes are very abrupt and in many places are very much broken by kettle holes, knobs, and hogback ridges. Some of these ridges extend one-half mile or more out into the marshes, above which they rise 50 to 70 feet; some of the crests are so narrow that two teams could not pass upon them; and some of the slopes drop down at angles of 30° to 35°.

The character of the deposits is shown by the following wells on this terrace:

Log of W. S. Watson's well at Little Prairie, Wis.

	Feet.
Gravel	40
Hardpan	40
Sand	40
Hardpan	2
Gravel	4
	126

Log of Robert Cross's well, 2 or 3 miles south of Little Prairie, Wis.

	Feet.
Stony clay	16
Gravel and sand	125
Stony clay	?
Gravel	?
	254

Log of McKee Bros.' well, 5 miles west of East Troy, Wis.[2]

	Feet.
Blue clay	66
Sand	160
Hardpan	4
Layers of hardpan 3 or 4 feet thick, alternating with layers of sand	171
Rock	3½
	404½

There is nothing to show how much of the drift penetrated by these wells is to be referred to the advance and how much to the retreat of the Delavan lobe, nor what part may have been deposited during earlier stages of glaciation.

Drainage.—The drainage from the Green Bay Glacier southwest of Palmyra probably escaped to Rock River by the low tracts bordering the inner margin of the Milton moraine; that from the Green Bay front east and northeast of Palmyra by the interlobate angle near Eagle; and that from the front of the Delavan lobe as far south as the divide south of Sugar Creek valley through the Turtle Creek outlet near Delavan and thence to Rock River at Beloit. A part of this water reached the Turtle Creek outlet near Delavan by the way of the Jackson Creek valley through the Elkhorn moraine, south of Elkhorn. South of the

[1] U. S. Geol. Survey Prof. Paper 34, pp. 57-59, pls. 10, 11, and 12, 1904.

[2] Information furnished by W. L. Thorne, well driller, Whitewater, Wis.

Sugar Creek valley the glacial waters continued to flow to the Nippersink outlet at Genoa Junction. The gravel deposits on which stand the villages of Springfield and Lyons were probably formed as deltas at the debouchures of the valleys by the water coming from the elevated area to the north. About this time also the gravels underlying Gardners Prairie, northwest of Burlington, were probably deposited as outwash.

Two miles west of the village of Vienna a small valley heads in a sag in the south slope of the Sugar Creek valley and leads thence southward to the White River bottom northeast of the village of Lyons. Although this valley is eroded to a depth of 40 to 100 feet, it has scarcely any area tributary to it except its own immediate slopes; it contains no stream, and it shows very little evidence of recent erosion, such as marks the valley one-half mile west. Evidently it was not cut by postglacial erosion but was probably developed by glacial waters.

No single position of the eastern ice front is definitely shown, and very likely no definite moraine was formed, the deposits commingling with and being buried by the gravels swept along by the waters escaping from the diverging ice fronts. A few separated higher tracts which rise above the level of the surrounding plain in the towns of Eagle, Troy, and East Troy may perhaps be regarded as the higher parts of such morainal deposits.

The present condition of the gravel deposits east of the Elkhorn and Kettle moraines indicates that a stage of erosion followed the first deposition. The upper terrace in the vicinity of Eagle is bordered on the east by a second and lower, broad, flat, gravel terrace, the two being connected by a short abrupt erosion slope 30 to 40 feet in height. This second terrace, which extends northward to a point about 1 mile southwest of North Prairie, has, in turn, been partly cut away by erosion and has developed a third and still lower terrace. The relations of the second terrace to the first seem to indicate that when the latter was formed the Green Bay Glacier had been melted back from the Kettle moraine so as no longer to discharge gravel-bearing waters eastward across the crest. Possibly the ice front then stood at the morainal belt extending northeastward from the vicinity of Palmyra. The ice front on the east must also have been melted back to a position east of North Prairie, Jericho, and Eagleville. A strongly developed terminal moraine extends northward from Genesee and east of Wales. If the west front of the Delavan lobe stood at this moraine, joining the margin of the Green Bay Glacier somewhere north of Wales and extending thence southward and eastward in a broad curve to a junction with the main front of the Lake Michigan Glacier a few miles north of Waterford, conditions would have been suitable for the development of this second gravel terrace.[1] The gravel deposits north of East Troy are very much pitted by large and small depressions, which, with a line of morainal hills between points 2 and 5 miles to the east, may mark the position of the margin of the shrunken Delavan lobe. With the ice in this position and extending southward along the Fox River valley, the glacial waters could have found their way to the Nippersink outlet at Genoa Junction by flowing southward over the sites of the villages of North Prairie, Jericho, Eagleville, and Troy Center, swinging eastward through the valley of Sugar Creek, flowing southward from Vienna, past Lyons, and traversing the passages through the morainal belts between Burlington and Lake Geneva. The recession of the Green Bay ice front from the Kettle moraine would reduce the amount of detritus in the waters, and the opening of this outlet via the Sugar Creek valley and Nippersink Creek, which is considerably lower than the outlet by the way of Turtle Creek, would have favored decreased deposition and increased erosion by the glacial waters in the towns of Genesee, Eagle, and Troy. That the depressions in the gravel plain were not filled up is evidence that the buried masses of ice remained intact. Glacial waters discharging westward by the passages between the hills in Waterford and Rochester townships and through the morainal deposits of western Racine and Kenosha counties also joined this flow to the Nippersink outlet at Genoa.

Origin of the Sugar Creek valley.—The relationships of the Sugar Creek valley, which cuts through the elevated ground-moraine area northeast of Elkhorn, are rather peculiar. The amount of erosion required for its excavation is equaled, in the area of the later drift examined by the writer, by few valleys with so small an

[1] U. S. Geol. Survey Prof. Paper 34, pp. 60-63, pl. 13, 1904.

area of tributary drainage. Its flat, marshy bottom is one-eighth to nearly one-third mile wide, yet contains only a meandering rivulet so small as to be out of all proportion. Sugar Creek heads in a narrow, marshy tract north of Elkhorn, which is also drained by the head of Turtle Creek on the west and by the head of Honey Creek on the north. The valley leads from low marshes 900 to 920 feet above sea level to a low area northwest of Burlington having an elevation of 760 to 800 feet. To reach this area it cut through an elevated track, which, in its highest part on the immediate crests of the valley slopes, is 1,040 to 1,060 feet above sea level. Moreover, but very little of this elevated area is tributary to this valley. Thus it is evident that the valley of Sugar Creek could not have been developed under ordinary conditions of erosion. Possibly drainage conditions associated with the melting of the Illinoian or early Wisconsin ice sheets may have resulted in the erosion of a valley which was only partly refilled by drift at the later advance of the ice, leaving a depression in the drift surface. Such a sag would be deepened by water flowing westward to Turtle Creek from the retreating front of the Delavan lobe so long as the glacier lay across the line of the valley. The valley may thus have been extended eastward, trenching the highest part of the area nearly to the level of the Turtle Creek valley, northwest of Elkhorn. When the ice had withdrawn entirely from the line of the valley the drainage began to flow to the lower area to the east, and the valley was further deepened by cutting back in the opposite direction. In this manner it is probable that the divide was cut down until it was lower than the valley leading to Turtle Creek outlet near Delavan. As soon as this was accomplished the whole of the glacial drainage from the ice fronts north of this newly opened valley was diverted eastward to the valley leading to the Nippersink outlet at Genoa Junction, Sugar Creek valley was still further deepened, and the Turtle outlet was abandoned.

RECESSION TO THE LAKE MILLS MORAINIC SYSTEM.

THE MORAINES.

GENERAL RELATIONS.

Lying within the curve of the Milton moraine are other lines of morainal deposits marking successive positions of the front of the melting Green Bay Glacier. Some of these may be grouped into systems, having apparently been more or less closely related in time of deposition. The first group may be designated the Lake Mills morainic system from the notable development of the morainal deposits and the merging of the several constituent moraines in the region of Lake Mills, Jefferson County.

In discussing the Delavan lobe and associated phenomena[1] the writer termed the outermost of these slight moraines the "Hebron moraine"; but in view of the somewhat indefinite nature of it and of its companion moraines through a large part of their extent and of the uncertainty of the correlation along the several lines it seems better to give a name to the whole system rather than to try to define each member separately.

In western Waukesha County and at the beginning of their curves from southwestward to westward through Jefferson County the several lines of deposits are fairly continuous and, in part, constitute well-developed terminal moraines; but along the southwestern and western sides of the lobe the deposits are so slight and interrupted by such wide intervals that it is only when brought together on a map and studied in all their relations that their real significance appears. When thus delineated they are seen to mark the continuations of the better-defined moraines on the southeast side of the lobe.

The amount of recession of the south and west fronts of the glacier, measured from the outer margin of the Johnstown moraine to the outermost of these morainal belts, was 15 to 20 miles. In the western half of Waukesha County the several belts converge and join the interlobate moraine in the Oconomowoc Lake region. The amount of recession of the west side during the formation of this morainic system was generally 7 to 12 miles and in places as much as 15 miles, or about twice as great as on the southeast. On the east side the ice continued pressed against the interlobate moraine. It thus appears that the bilateral asymmetry of the glacier developed during the maximum deployment of the ice was somewhat reduced as the margins of the lobe contracted when melting.

Between the Oconomowoc region and the region of Lake Mills (where the deposits of all

[1] U. S. Geol. Survey Prof. Paper 34, p. 63, 1904.

the lines appear to merge into each other) four more or less distinct lines of deposits mark as many positions of the ice front. From Lake Mills region to Marquette County only three lines can be distinguished. Northward through Marquette County the outer (western) line is generally strongly marked, but the inner (eastern) lines are not clearly separable.

GEOGRAPHIC DISTRIBUTION.

OUTERMOST MORAINE.

The outermost member of this system separates from the interlobate moraine at the basins of Pine Lake and Lake Nagawicka, north of Delafield, and extends westward to Oconomowoc as a broad morainal belt surrounding and including the basins of Oconomowoc and Upper Nashotah lakes. In this part it overlies the great buried valley that Rock River eroded in the "Cincinnati" shale. The well at Patrick Valentine's summer home, near the west shore of Oconomowoc Lake, penetrated 270 feet of drift without reaching the bottom of this valley. Near Oconomowoc the moraine bends southwest and, including Silver and Golden lakes, extends thence to Bark River south of Sullivan. The larger basins resulting from the melting of ice blocks left buried along the line of this moraine are now occupied by lakes with the following maximum depths: North Lake 73 feet, Mouse Lake 66 feet, Pine Lake 90 feet, Okauchee Lake 95 feet, Upper Nashotah 51 feet, Oconomowoc Lake 62.5 feet, and Silver Lake 4 feet. All are surrounded by abrupt gravelly shores. The characters of the lake basins of this area are shown on a hydrographic map issued by the Wisconsin Geological and Natural History Survey. The ice blocks in all these lake basins must have continued until after the surrounding moraines and terraces were completed, otherwise the depressions would not have remained unfilled with drift.

Along the south line of the moraine lies a flat terrace 6 or 7 square miles in extent, underlain by gravels washed from the morainal front. These gravels are exposed at several points below a thin coating of loamy clay. Near the moraine the terrace is pitted with numerous depressions, farther away its surface is very regular and nearly as flat as a floor. The gradation from the morainal front to the terrace is well shown between Oconomowoc and Silver lakes.

On the north side of the extensive marshes which border Bark River and Scuppernong Creek the moraine extends in a broad curve to the vicinity of Fort Atkinson. In some parts between Hebron and Fort Atkinson the moraine is strongly marked by gravel knolls and kettle holes and some small tracts of bordering outwash gravels. In the vicinity of Hebron the drumloidal topography is not greatly obscured but in T. 6 N., R. 16 E. (Sullivan Township), the morainal ridge is more bulky, the drumlin contours disappear, and some pitted tracts occur.

One of the notable features of this moraine is its blocking of the northern branch of the preglacial Rock River valley east of Fort Atkinson. Numerous wells in the lower parts of this deposit penetrate 100 to 250 feet of drift. Not all of this filling is to be credited to this moraine; doubtless much of it was deposited during the glacial advance or even earlier. Wells in Fort Atkinson and vicinity show equal amounts of drift in the ground-moraine tracts, but the morainal ridges were piled up at this stage of the retreat.

Morainal deposits occur about the south margin of the drumlin-bearing upland of Oakland and northeastern Sumner townships (Tps. 6 and 5 N., R. 13 E.) and extend northward from the vicinity of Sumner along the east side of the valley of Koshkonong Creek to Cambridge and Lake Ripley. The Koshkonong Valley was probably freed from ice at least as far north as Rockville, south of which the glacial waters built the gravel terrace in which Koshkonong Creek cut its channel on its way to join the new Rock River.

From the vicinity of Fort Atkinson the morainal deposits continue northward through the western part of T. 6 N., R. 14 E. (Jefferson Township), and thence westward through the northern part of Oakland Township, where they merge with a great morainal tract between Ripley and Rock lakes. In this part the drift ranges from nothing to 205 feet in thickness, completely obscuring the topography of the underlying rock surface. The thickest drift penetrated is in Charles Schimming's well, 5 miles west of Jefferson, in the SE. ¼ sec. 1, Oakland Township. Albert Hummel, well driller, Fort Atkinson, states, however, that the greater part of the 205 feet of drift at this place is blue clay, which is probably not to be referred to this morainal deposit.

From Cambridge the ice front extended in a broad curve through Dane County and entered Columbia County about 3 miles west of Morrisonville. Through this distance of more than 30 miles the only indications of a halt of the glacial margin are small deposits of gravelly drift forming low ridges or irregular sag-and-swell or kame-and-kettle patches, most of which are not continuous for more than 2 or 3 miles. The principal deposits along this line in Dane County border the marshes of the Mud Creek valley west of Cambridge or lie between the branches of Door Creek south and southwest of Cottage Grove, near the east end of Lake Monona, at the golf grounds east of Lake Mendota, in and north of the marsh north of Mendota, in the vicinity of Norway Grove, and 1 to 3 miles west of the railway at Deforest and Morrisonville. Near Norway Grove kame and kettle topography is well developed over an area of 3 or 4 square miles. In Columbia County the position is shown by narrow morainal strips one-half to 1 mile west of Arlington, at Poynette, and thence northward along or near the railway to the big marsh between Fox and Wisconsin rivers east of Portage. With these are to be grouped the pitted sandy deposits which underlie Portage and extend northwestward for several miles on the north side of the river. Wells in Portage show 50 to 120 feet of sandy drift overlying the sandstone.

Northward, beyond the sandy and marshy flat, little evidence of the position of the ice front appears south of Neenah Creek, a mile southeast of Briggsville. North of the creek a strong morainal ridge 50 to 120 feet in height and one-fourth mile to a mile or more in width may be traced almost continuously northward to Waushara County. It spreads over half the width of northern Oxford Township (T. 15 N., R. 8 E.) and merges on the west with the deposits grouped with the Milton moraine. Narrowing again in Westfield Township it is separated by a low tract or basin from the earlier moraine. Along the line between Springfield and Newton townships it is strongly developed as a ridge about a mile in width, which contrasts markedly with the low areas on the east and on the west, and (as in Westfield Township) it is separated from the earlier moraine by an elongated basin which must have been occupied by a glacial lake. In southern Waushara County this moraine merges with those on the west in one continuous belt 7 miles in width.

When the ice front occupied the line of morainal deposits thus sketched the waters of the upper Wisconsin Valley must have had an outlet about the east end of the Baraboo Bluffs, but the presence of lacustrine clays between this moraine and the Milton moraine indicate that for some time at least the ice must have maintained the barrier at the east end of the Baraboo Bluffs and have held the lake waters in these intermorainal basins. Charles Koplein, well driller, near Oxford, and L. A. Perkins, driller, at Westfield, informed the writer that in their opinions the heavy beds of clay underlying intermorainal tracts do not extend beneath the morainal ridges.

No very satisfactory information was obtained about wells in the highest central parts of the moraine. It seems probable to the writer that in places, at least, an earlier deposit of clay must underlie the moraines, in addition to the beds which were laid down in the intermorainal tracts when the morainic ridges were being formed.

Like the moraines to the west this one in Marquette County is composed of very sandy drift. Pebbles and bowlders are not very abundant in the drift and do not generally include much limestone. One estimate of pebbles, however, at a point 1½ miles southeast of Oxford, showed the following percentages:

Composition of drift pebbles, sec. 22, T. 15 N., R. 8 E. (Oxford Township).

Limestone	61
Chert	5
Quartzite	5
Local crystallines	5
Foreign crystallines	24
	100

About 3 miles southwest of Westfield, in sec. 23, Westfield Township, large bowlders of coarse granite (one of them measuring 8 by 10 by 15 feet) are so numerous as to suggest the presence of a buried ledge in the vicinity, though none of them appear to be in place. They may have come from some part of the Montello ledge, though they differ somewhat from the rock exposed in the quarries. Similar bowlders are abundant 2 to 3 miles farther northwest in the Milton moraine in an area south and southwest of Lawrence.

Two miles southeast of Oxford, in the NE. ¼ sec. 22, where the ridge is 80 to 90 feet high, a cut was being made in the crest of this moraine for the new grade of the Chicago & Northwestern Railway when visited by the writer in 1910. To the depth of 30 to 35 feet, the limit of excavation then accomplished, only clean sand was exposed stratified in layers dipping westward. The foreman in charge informed the writer that test holes showed the material below a depth of 40 feet to be mostly clay. At the east end of the cut in the lower slope some red clay was mixed with the sandy drift, as if a bed of clay had been overridden by the ice.

In this connection may be mentioned an exposure in one of the cuts about a mile farther southeast (three-fourths mile northwest of the Chicago & Northwestern station at Buffalo). The cut is through the crest of a drift ridge just north of the big marsh. Most of the 10 to 15 foot section is of sand and gravel, stratified in beds dipping east or southeast, like a lake delta or bar. (See fig. 17.) At the southeast end, toward the marsh, the stratified sand and gravel is overlapped by a bed of laminated red clay, inclosing some stones at the bottom, which thickens southeastward to 8 feet and passes below the bottom of the cut. Overlying both the clay and the sand and gravel is 3 to 4 feet of sandy till inclosing numerous large crystalline bowlders, some of which are entirely disintegrated. The upper part of the clay bed is weathered and discolored and has its stratification destroyed to a depth of 4 feet, below which the clay is beautifully laminated. The structure and relations suggest that a bar or delta in a lake was covered by a deposition of fine red lacustrine overlapping silts and was then overridden by glacier ice advancing to the terminal moraine, whose crest is nearly 2 miles farther west. Such phenomena lead to the suggestion that this moraine marks the limit of readvance of the ice after an interval during which the glacial front had been melted back for some distance.

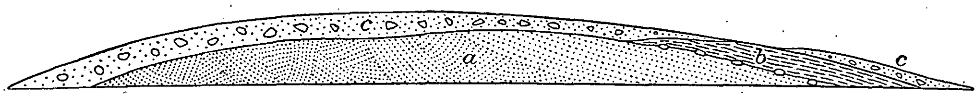


FIGURE 17.—Glacial and glaciolacustrine deposits exposed in Chicago & Northwestern Railway cut three-fourths mile northwest of Buffalo station. *a*, Cross-bedded sand and gravel; *b*, laminated red clay; *c*, sandy glacial till.

Red clay is exposed at several places in the low tract west of the moraine of the Lake Mills system in Tps. 14 and 15 N., R. 8 E. (Douglas and Oxford townships). One of the best exposures is near Neenah Creek, about a mile northeast of Briggsville, where, beneath the sandy soil, the writer observed 16 feet of laminated calcareous red clay. Several wells on this low tract as far north as Oxford are reported to penetrate 75 to 100 feet of red clay overlying sand. From the basin in Westfield thicknesses of 70 to 130 feet are reported. In places, especially near the foot of the morainal ridge, the clay is overlain by considerable sand; and at several places about the margins of the elongated basin west of the moraine in T. 17 N., R. 8 E. (Springfield Township), similar red clay is exposed. A. F. Miller's well, about 1½ miles north of Westfield, on the lower western part of the moraine, is said to have penetrated nearly 130 feet of clay beneath 30 feet of sand.[1]

SECOND MORAINAL LINE.

A very slight moraine, branching from the outermost moraine near Sullivan, in eastern Jefferson County, marks the position of the ice front after a farther recession of 1 to 3 miles. This second moraine lies in a broad curve across a well-marked drumlin topography. Where it crosses the big marsh east of Jefferson its crest appears as a narrow ridge extending out about a mile into the west side of the swamp, but for half a mile the moraine is entirely submerged in the filling of the great preglacial valley, which is here more than 200 feet deep. Beyond this marsh the moraine emerges and may be traced continuously for nearly 8 miles northwestward across Rock River and through the Jefferson County farm to the southwestern part of T. 7 N., R. 14 E. (Aztalan Township), as a somewhat pitted ridge of drift lying transverse to the trend of the neighboring drumlins.

Farther west, in the southern part of T. 7 N., R. 13 E. (Lake Mills Township), the position of

[1] L. A. Perkins, driller, Westfield, authority.

the ice front is marked by an abrupt irregular ice-contact slope which forms the margin of a broad pitted deposit built against the ice wall of the glacier as it lay in the basins which are crossed by the Chicago & Northwestern Railway between Lake Mills and London, and which are now occupied by big marshes and swamps. The deposit seems to have been formed in a slight reentrant angle of the ice front. Along its east side is a strongly marked kame-and-kettle topography, and about one-fourth mile west of its east margin its surface grades into a nearly flat pitted plain resembling an outwash terrace. This grades again westward into morainal topography.

Like the line of deposits next outside, this line is very poorly developed along its broadly curving course through Dane County. Pitted gravel deposits occur along and south of the railway between London and Deerfield. East of Cottage Grove the road north of the railway crosses the marshes on this moraine. Near the middle of the south line of T. 8 N., R. 11 E. (Sun Prairie Township), the continuation of this marginal deposit is joined by a northeast-southwest line of gravel ridges and knolls which is perhaps the continuation of the Cottage Grove esker. Morainal drift surrounds the drumlins northeast of Burke and from this gravels were washed down the valley traversed by the railway southwest of the station. Rock is exposed in the hill slopes east and west of Burke, but within a mile to the northeast the drift ranges in thickness from 40 to 115 feet. A very faint development extends the line from Burke to Token Creek. One to two miles east of Windsor and Deforest there is a marginal ridge about 40 feet high and 3 to 4 miles long. Deposits marking the line may be traced northward in Columbia County to Wyocena, beyond which, to Pardeeville, the moraine is well developed and is bordered on the west by an extensive outwash terrace traversed by a road. Poorly developed morainal deposits bordering the Fox River marshes on the east extend this line northward to the broad morainal tract between Packwaukee and Montello. Morainal topography with many big kettle holes and numerous ponds is markedly developed west of Montello River in adjacent parts of Packwaukee, Montello, and Harris townships, Marquette County. Farther north, in the towns of Harris and Newton, there are some patches of what appear to be morainal deposits, but the position of the ice front is not distinctly traceable.

THIRD MORAINAL LINE.

A third line of similar slight deposits branches from the second moraine just south of Oconomowoc, indicating a further recession of the south and west fronts of the glacier while the interlobate angle maintained its position south of North Lake. According to Joseph Eiden, well driller, Oconomowoc, a well on Mr. Peck's farm on the hill a mile south of Oconomowoc penetrated sand and blue clay to a depth of 218 to 220 feet. W. S. Bolson, well driller, Oconomowoc, informed the writer that Mr. Smith's well on the hill a mile southwest of the village encountered 2 feet of soft black muck beneath 60 feet of sand and gravel and above 50 feet of blue clay. H. C. Melcher's well on the same hill about 50 feet lower down the northeast slope passed through 135 feet of sand and hardpan in alternating layers to gravel at the bottom without reaching bedrock. The line of pitted deposits is bordered on the south by an outwash terrace extending about 3 miles west from the north side of Silver Lake. From this an interrupted line of pitted gravel deposits may be traced between the marshes and drumlins past Helenville to Jefferson.

The hills on which stand the Catholic church and convent east of Jefferson and the hill in the northeast part of the city are composed of drumlins partly covered by morainal deposits. Wells at the convent and residence of the priest, on the hill a mile east of the city, penetrated 301 and 288 feet, respectively, mostly of sand, according to the statement of Albert Hertig, well driller. This shows that the deposits overlie an ancient buried valley.

At this stage a lake must have occupied the basin of the big swamp east of Jefferson, and a smaller lake held in by the moraine south of Jefferson must have deposited silt that produced the laminated clays used by Kemmeter Bros. and the Jefferson Brick & Tile Co. in the the manufacture of brick and drain tile. When visited by the writer the clay pit just south of the railway bridge exposed 5 feet of beautifully laminated buff clay with some interlaminated sand, grading downward into dense blue clay. The laminæ are finely undulating and in places crumpled. The outlet of this lake southward through a sag in the morainal barrier located Rock River in its present course across a broad buried rock ridge between Jefferson and Fort Atkinson instead of through the big swamp above the preglacial valley 2 to 3 miles farther east. The drift is very thick at both Jefferson and Fort Atkinson, but it is much thinner on either side of the stream between the two places, and at one point limestone is exposed in the river bank. About this time Crawfish River came into existence, heading at the ice front somewhere in the vicinity of the railway bridge south of Aztalan.

At this time also the deposits which immediately surround Rock Lake and underlie the village of Lake Mills were formed.

From Rock Lake to Sun Prairie only scattered patches of pitted gravels among the drumlins and marshes mark this third line of halt. Farther northwest it can not be distinguished.

FOURTH MORAINAL LINE.

Within the curve of the morainal belts described above another line, similar in character, apparently marks a distinct stage in the recession of the ice front. It is strongly developed north of the lakes in T. 8 N., R. 17 E. (Oconomowoc Township) and extends thence eastward into the adjacent town of Merton. North of North Lake it swings northward and continues, parallel to the west front of the interlobate moraine and separated therefrom by a narrow valley, to the vicinity of Pike Lake. North of Thompson it is joined by a somewhat discontinuous branch moraine representing a slightly later stage of development.

This moraine is 1 to 3 miles wide, except immediately south of Pike Lake, where it sharply narrows to a single abrupt ridge barely 40 rods wide, which marks the point of divergence of the ice front from the interlobate moraine at the time of its formation. For the rest of its course it consists of a broad ridge 20 to 100 feet high, whose surface is generally marked by a sag-and-swell topography. In the town of Oconomowoc some considerable ice-block basins occur, in which lie Lac La Belle and Fowler and Ashippun lakes. A well at Thompson was thought to reach bedrock at a depth of 96 feet, but several others 100 to 175 feet in depth do not pass entirely through the drift. So thick is the drift along this moraine and adjacent to it that the location of the west margin of the Niagara dolomite has not been determined. It may be that throughout most of its extent south of Thompson the moraine overlies the buried valley traced farther south. As in the other moraines most of the exposures show coarse gravels below an irregular thickness of till.

West of North Lake this moraine is bordered on the south by a well-developed outwash terrace of several square miles. On this terrace, which extends to the west shore of North Lake and to the north and west shores of Okanchee Lake, stands the village of Stone Bank. The basin of Lac La Belle is surrounded by morainal and outwash gravel deposits. (See Pl. XXXI, *A*.)

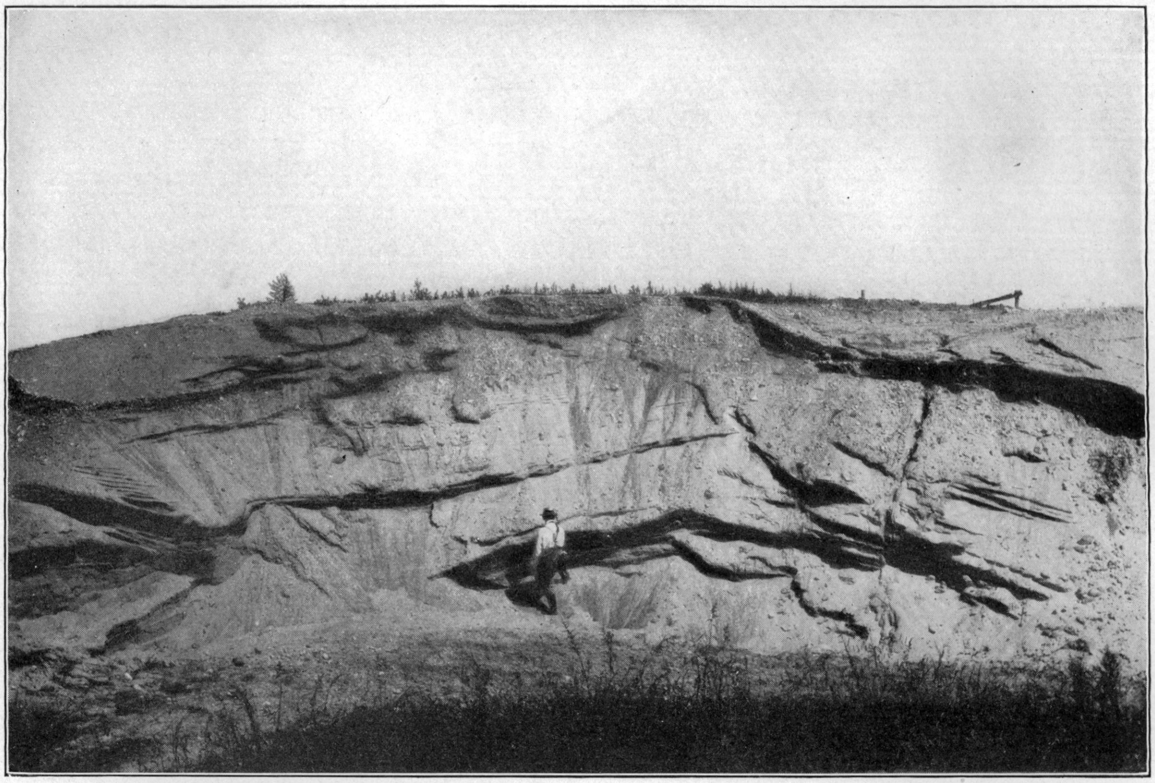
The continuation of this moraine is a discontinuous line of slight gravel deposits which may be traced among the marshes and drumlins from Lac La Belle southwestward past Concord and Farmerton and across the railway 1 to 2 miles west of Helenville. The moraine, though slight, is continuous nearly across the southern part of Farmington Township. The ice front must have curved northwestward and have lain somewhere near Jefferson Junction and Aztalan and have furnished the headwaters of Rock River and Crawfish River. North of Lake Mills the ice front lay along a morainal deposit which is much broken by kames and kettles and by irregular basins occupied by tamarack swamps. Through the southwestern part of Waterloo Township, Medina, and northeastern Sun Prairie this line, like the others, is to be traced only by patches of morainal deposits among the marshes and drumlins. One and one-half miles northeast of Sun Prairie, in secs. 28, 29, and 33, T. 9 N., R. 11 E. (Bristol Township), a sharp little morainal ridge 30 feet in height and about 2 miles long carries abundant crystalline bowlders on its surface.

From just east of Leeds Center, Columbia County, a very slight moraine may be traced continuously northward about 8 miles in the towns of Leeds and Lowville. Two small lakes were held west of this moraine.

A bit of moraine about 2 miles in length is found in the southeastern part of T. 12 N., R. 10 E. (Wyocena Township), but north of this scarcely a trace appears south of Montello Township, Marquette County, northeast of Observatory Hill. Here a morainal deposit

A. KAMES 3 MILES NORTHWEST OF OCONOMOWOC, WIS.

B. ESKER 2 MILES SOUTHEAST OF RANDOLPH, WIS.



A. TRANSVERSE SECTION OF ESKER 2 MILES SOUTHEAST OF RANDOLPH, WIS.

B. LONGITUDINAL SECTION OF ESKER THREE-QUARTERS OF A MILE WEST OF WATERLOO, WIS.

separates the two big marshes and continues northward, traversed by the east road, to the river at Montello. South of the river in the towns of Packwaukee and Montello (T. 15 N., Rs. 9 and 10 E.) the lines of discontinuous morainal deposits merge and continue north of the river in a broad tract about 6 miles in width. This area south of the river is very sandy and is pitted by many large and small ice block depressions, in the larger of which are numerous lakelets. The depths of drift penetrated by wells both north and south of the river indicate the presence of a considerable buried valley. The character of this filling, much if not most of which is probably of earlier date, is shown by the following logs:

Log of village well, Packwaukee, Wis.[1]

	Feet.
Sand	20
Blue clay, stoneless	76
Gravel.	

Log of J. Rockefeller's well, on north bank of river 2 miles east of Packwaukee, Wis.[2]

	Feet.
Sand	40
Clay, stoneless	90
Sand	10
	140

Log of Charles Tagatz's well, near south bridge, Montello, Wis.[2]

	Feet.
Black soil	20
Sand with logs of wood.	
Clay, stoneless	130
Sand	10
	160

Many wells near the river penetrate the heavy bed of blue clay beneath a coating of sand and overlying sand or gravel. The lower bed is the source of the fine artesian flows at Packwaukee and Montello.

What appears to be a morainal deposit extends northward between the marshes in the western part of Shields Township, into Crystal Lake Township (T. 17 N., R. 10 E). The topography is well marked in only a few places.

INTERLOBATE ANGLE.

When the last of the deposits of the Lake Mills morainic system were being formed, the southeast margin of the Green Bay Glacier appears to have melted back from the interlobate moraine as far north as the town of Barton, Washington County, 4 or 5 miles west of West Bend.

Between Pike Lake and the town of Barton only the lake basins and intervening depressions separate these deposits from the interlobate moraine. In southern Hartford Township (T. 10 N., R. 18 E.) the former bear southwestward and extend through the town of Ashippun. Southwest of Pike Lake the deposits are spread out in low relief and are interlaced by irregular depressions occupied by tamarack swamps and marshes. One well in this part penetrated 278 feet of drift and others 100 to 200 feet, so that it is probable the ice here lay across a continuation of the buried ancient valley. Between Cedar Lake and the valley traversed by the Wisconsin Central Railway is a bulky deposit whose elevated surface is marked in part by sags and swells and larger depressions constituting terminal-moraine topography and in part by the gentle undulations of a ground moraine, so that the boundary between the terminal and ground moraine deposits is doubtful. The whole was probably deposited at or near the margin of the ice. Many wells in this tract penetrate 75 to 280 feet of drift without reaching rock.

In T. 9 N., R. 17 E. (Ashippun Township) the ice margin appears to have shifted somewhat, for one line of morainal deposits may be traced southeastward to the northeastern and thence westward to the northwestern part of Oconomowoc Township. At several places along this line (east of Monterey, for instance) lie pitted terraces of outwash gravels.

Another discontinuous line of deposits extends south, through adjacent parts of Ashippun and Lebanon, Ixonia, and Oconomowoc townships, to the fourth morainal belt west of Oconomowoc, but can not be traced farther west, unless it is represented by certain morainal deposits in Marquette County. In Mecan Township a strongly marked morainal ridge extends westward from the bend in Fox River, spreading north and south in Montello and Shields townships (Tps. 15 and 16 N., R. 10 E.). Farther north a morainal belt lies between the marshes for 2 to 3 miles south of Germania. Some patches of like deposits in southern Waushara County possibly belong to the same belt.

[1] Data from George Kinney, Packwaukee, Wis.
[2] Data from Ben Neck, well driller, Montello, Wis.

LITHOLOGIC COMPOSITION OF THE LAKE MILLS MORAINIC SYSTEM.

In order to ascertain the distribution of the constituents of the drift nearly 10,000 pebbles were sorted and counted, and their percentages noted at 59 different places along these several morainal belts within the Milton moraine. The per cent of foreign material, principally crystalline rock from Canada, is from 3 to 32, but in most analyses is less than 4 per cent above or below 11.45, the average of the whole. In only 5 analyses is it 18 per cent or more. Examination of the local material shows that here, as in the Johnstown and Milton moraines, the geographic distribution of the pebbles is as would be expected from the relations of the ice to the belts in which the several formations were exposed to erosion. (See Pl. I, in pocket.) A very little material apparently from the Devonian formation near the shore of Lake Michigan was found in the region of Hartford and it may have been derived from the drift of an earlier glacier which invaded the area from the northeast. Niagara dolomite ranging from 90 to 47 per cent occurs as far west as eastern Jefferson County and from 11 to 15 per cent as far as Koshkonong Township. Some of this also may have come from the earlier drift. Farther west it is entirely absent. Decrease in the Niagara constituent is accompanied by a reciprocal increase in the percentage of Galena and Trenton material, which in Waukesha County ranges from nothing to 35. Westward through Jefferson County and into eastern Dane County the range is from 30 to 90 per cent, usually 75 to 85. The Lower Magnesian limestone is first distinguished in western Jefferson County in small percentages, but near Burke and Madison it becomes the predominant constituent, replacing the Galena and Trenton. From the vicinity of Madison northward over the marginal upland underlain by the Lower Magnesian formation and thence down over the lower sandstone area, and northward into Marquette County, north of the Fox River, it continues to predominate, ranging from 60 to 90 per cent. The drift over the sandstone areas is generally very sandy, but the sandstone is so friable that it contributes comparatively few pebbles, and does not appear in its true percentages in these estimates, which are based on pebbles. The same is true of the "Cincinnati" shale, which contributes principally to the clayey matrix of the drift. The morainal drift, however, was so largely handled and assorted by glacial waters that the finer silts were removed and deposited in bordering lakes and streams. The quartzite in the drift of Waukesha County and most of Jefferson County is very small in amount, commonly less than 2 per cent, and is probably all foreign. In the lee of the Waterloo quartzite ledges, which outcrop in northwestern Jefferson County and southwestern Dodge County, local quartzite becomes a notable constituent, the estimates showing 4 to 14 per cent; and in many places, in the bowlder fans spread out in the lee of these ledges, quartzite bowlders are very abundant on the surface of the drift. On the west, in Dane County, the quartzite percentages range from nothing to 1½ and so continue northward to Marquette County, where they again rise to 3 to 5. In Columbia County north of Portage and in Marquette County local granites and porphyries are derived from crystalline knobs which protrude through the lower Paleozoic formations.

ESKERS.

STRUCTURE AND RELATIONS.

Associated with the Lake Mills morainic system are several eskers, which mark the positions of streams that discharged at the ice front and filled their ice-walled channels with stratified gravels. The final melting of the ice walls left more or less continuous, sinuous gravel ridges, which still persist. A few mark the positions of streams discharging when the ice front stood at the outermost of the Lake Mills moraines, but most of them appear to be correlated with the formation of the inner line of deposits. These eskers, small as many of them are, are important sources of supply for gravel for local use on the country roads.

One esker, which extends southwestward through the cemetery a mile northwest of Cottage Grove, has a length of about a mile and merges with morainal deposits at the south end near the railway. Though small it is an excellent example of sinuous esker. A second small esker north of the railway in secs. 12 and 13, T. 7 N., R. 10 E. (Blooming Grove Township), 3½ miles east of Lake Monona, is interesting principally from its relations to the slopes of drumlins, which it borders. In one place the slight sinuous ridge curves against and then away from the drumlin slope, as though the stream was diverted by encountering the drift hill beneath the ice. An esker that crosses the Columbia-Dane county line one-half mile north of Morrisonville can be traced for about 2 miles in a sinuous course somewhat south of west toward the morainal deposits, but not to connection with these. A cut on the road north of the village exposes 15 feet of gravel containing pebbles ranging from fine to 8 or 10 inches in diameter.

A line of small gravel ridges near the road north of the railway about a mile west of Cambria in sec. 1, T. 12 N., R. 11 E. (Springvale Township), indicates where a stream flowing off the upland to the northeast dropped its gravels beneath the ice.

From about 2 miles southeast of Randolph, in the SE. ¼ sec. 8, T. 12 N., R. 12 E. (Westford Township), a line of sinuous gravel ridges may be traced, with numerous interruptions, southwestward for nearly 5 miles to the NE. ¼ sec. 22, Courtland Township. One of the finest bits of this esker, where it is 20 to 30 feet high, may be seen west of the road at a point 2¼ miles south of Randolph. (See Pl. XXXI, *B*.) An excavation in the ridge just east of the road shows the material to be mostly sand, beautifully stratified, with cross-bedding and ripples and anticlinal dips. (See Pl. XXXII, *A*.) With the sand are 1 to 4 inch gravels. Excavations at numerous other places expose gravels.

Subglacial streams occupying the valleys now drained by Duck Creek in the southern half of Springvale Township left sinuous gravel ridges which may be traced for some distance. One is cut by the west-line road of sec. 21 just south of the creek; another is crossed by the west-line road of sec. 29 just north of school No. 2 and also by the middle-line road just south of the creek. These ridges are 10 to 20 feet high and are composed of gravel.

A similar small gravel ridge is crossed by the road between secs. 15 and 16, T. 11 N., R. 11 E. (Otsego Township).

What appear to be parts of a single esker system are gravel ridges extending discontinuously westward from the southwestern part of T. 11 N., R. 12 E. (Fountain Prairie Township) to the southeastern part of T. 11 N., R. 10 E. (Lowville Township). The first segment occurs about 2½ miles northwest of Fall River as a gravel ridge south of the railway in the NE. ¼ sec. 29, Fountain Prairie Township; and the second segment is about a mile farther up the valley on the south line of sec. 30 and extends nearly continuously for 1½ miles west through the south part of sec. 25, Otsego Township. Just west of the road it rises in a 50-foot hill of gravel. From sec. 25, Otsego Township, for 3 miles to the NE. ¼ sec. 32, only slight traces of the esker were seen, but beyond it may be followed in a southwesterly sinuous course for 2 miles—for 1 mile as a continuous ridge 15 to 20 feet high and 10 to 20 rods wide and then as a line of knolls. Several pits show the material to be a coarse cobblestone gravel poorly assorted and poorly or not at all stratified. The line of knolls has been traced to the southern part of sec. 36, Lowville Township, within 2 miles of the inner morainal belt. Where last recognized the elevation of the deposits is about 125 feet higher than those 7 miles farther east, yet the direction of flow of the esker-forming stream was undoubtedly westward.

From a point about 2 miles west of Columbus, the SW. ¼ sec. 10, T. 10 N., R. 12 E., a line of disconnected gravel ridges extends westward about 4 miles into sec. 13, Hampden Township. The best development of this esker is about 2½ miles west of Columbus in the SE. ¼ sec. 9, where the ridge is continuous for three-fourths mile. It is 15 to 30 feet high and is composed of stratified sand and gravel with anticlinal bedding. The pebbles exposed in the gravel pits are mostly coarse cobblestone with some bowlders a foot in diameter.

The location of another stream of glacial waters which flowed in an ice-walled channel is shown by a finely developed sinuous esker which heads near the middle of the north line of sec. 6, T. 8 N., R. 13 E., a mile north of Waterloo. The esker may be traced somewhat west of south across the county line and through the eastern part of Medina Township, a distance of about 5 miles. It varies considerably in height, the maximum being about 30 feet. Its sinuous course is very similar to that of existing streams. Mr. Hayhurst's gravel pit near the mill gives a longitudinal section that shows the stratified gravels dipping southward in the direction of flow of the depositing stream (Pl. XXXII, *B*); and Frank Langer's pit, one-fourth mile to the northwest gives a cross section that shows a rude anticlinal structure due to the slumping of the gravels at the sides as the ice retaining walls melted away. The material is mostly rather fine gravel and sand but contains many large cobblestones. The manner in which the esker follows the sag between the drumlins, meandering back and forth to and from their slopes, indicates that the stream flowed at or near the base of the ice and that the drift slopes on either side controlled the direction of flow. In its southern 2½ miles the esker is merely a line of low gravel knolls ending at the edge of the marsh.

Extending somewhat east of south from the vicinity of the railway bridge 2 miles southeast of Watertown through the southwestern part of Ixonia Township (T. 8 N., R. 16 E.) and the western part of Concord Township (T. 7 N., R. 16 E.) is a discontinuous line of sinuous gravel ridges, forming an esker system, whose total length is about 10 miles and whose longest continuous sections are about 1½ miles each. The esker ridges are 5 to 15 feet in height, and their sinuosities follow the winding course of the depositing stream. The esker is particularly well developed near Mrs. Mary Burdick's, in the W. ½ sec. 31, Ixonia Township. Numerous gravel pits expose the constituent material, which is principally gravel ranging from fine to cobblestones 10 inches in diameter. In places blocks of limestone 1 to 1½ feet long are included. The assortment and stratification are in most places poor.

From about 2 miles southwest of Horicon southward to a point 1 mile east of Juneau is a small esker-like ridge of gravel, and for 2 miles farther south some slight gravel deposits may indicate its continuation.

Similar small sinuous gravel ridges occur in the NW. ¼ sec. 16, T. 10 N., R. 15 E. (Clyman Township), 2 miles somewhat west of north and one-half mile west of Clyman. Two and one-half miles farther east a similar gravel ridge may be traced for three-fourths mile along the top of a low drumloidal ridge in secs. 13 and 24, and for three-fourths mile farther in the marsh.

The longest and one of the best developed of the esker systems of the area may be traced for 12 miles generally southeast from about 3 miles southeast of Horicon to 4 miles southwest of Hartford, where it merges with the last of the moraines correlated with the Lake Mills morainic system. Northwest of Neosho it consists of a line of short disconnected sinuous gravel ridges varying in height from 5 to 30 feet or more. Many of the fragments are one-half to three-fourths mile long; others are shorter; but altogether they appear to mark the course of a subglacial stream. The line separates from a broad morainal tract in the SW. ¼ sec. 15, T. 11 N., R. 16 E. (Hubbard Township), and for 1½ miles lies in a marsh tract now drained to Rock River at Hustisford. In the next 2 miles the gravel lies on a slightly higher undulating tract. The ridge is well developed 1½ miles west of Woodland where cut by the town-line road and where excavations, as at many other places, expose the coarse cobblestone gravel. From this point to one a mile north of Neosho (Rubicon Township, T. 10 N., R. 17 E.) the fragments of the esker are found in or near the large tamarack swamp. Near the corners a mile north of Neosho the ridge is narrow and abrupt, with a height of 30 feet and 30° side slopes. An excavation here shows the material to be coarse cobblestone gravel and small bowlders. The ridge is continuous from this point for a mile southward to the north side of the mill pond at Neosho. Thence southeastward for nearly 4 miles it is well developed, showing that the subglacial stream flowed along the valley in a direction opposite to that now taken by Rubicon River. Through about half of this 4 miles it is double, consisting of two sinuous ridges 10 to 20 feet high and a few rods wide, which alternately coalesce and separate so as to inclose depressions between them. In sec. 28 the ridge is single and is cut to pieces by erosion. In sec. 35, south of where the two ridges are cut through by the Rubicon, the ridges may be traced up the slope for 60 to 80 feet, where they unite, and go down the slope to the east as a single ridge, thence up the slope to the southeast into sec. 36, where they merge with the undulations of the terminal moraine. From its relations to the village of Neosho this esker may be designated the Neosho esker. A similar gravel ridge is cut through by Rubicon River at Saylesville, whence it may be traced southward near the foot of the lower east slope of the valley about one-half mile. There is some slight indication that originally it was continuous southwestward, joining the Neosho esker near the middle of sec. 35.

Cuts through these ridges show them to be composed principally of fine to coarse gravel. Most of the stones are less than 8 inches in diameter, but some are 1 foot to 1½ feet. The gravel is clearly water-washed material, largely well stratified, and the sinuous course of the ridge resembles that of a stream.

The manner in which these ridges follow the valley shows that the esker-forming stream must have flowed near enough to the base of the glacier to have its course determined very largely by the trend of the slopes of the depression in the drift which now constitutes the Rubicon Valley. These slopes rise 80 to 140 feet above the present stream, which appears to have done little in the way of deepening the original sag. That the esker-forming stream did not flow at the bottom of the valley seems probable from the fact that the esker climbs the side slope to a height of 60 to 80 feet to join the terminal moraine. The stream must have occupied a tunnel in the ice 60 to 80 feet above the bottom of the ice in the valley or have been forced to flow up the slope under hydrostatic pressure. The former hypothesis seems to the writer the more probable, though the latter is not untenable. The subsequent melting of the ice let down the gravel deposits in the ice tunnel as a ridge overlying whatever inequalities of drift surface happened to be below. Pits marking undulations of the crests of the ridges indicate buried ice blocks or inequalities in the bottom of the ice channel and in deposition of the gravel. To the disturbance and spreading of the gravels as the deposit was lowered by the melting of the underlying ice may be due the rather uncommon double-ridge character of the esker southeast of Neosho.

Other eskers of the region are shorter, some are more discontinuous, but none have their courses so obviously controlled by the topography of the ground moraine. The esker in sec. 4, T. 9 N., R. 17 E. (Ashippun Township), begins abruptly as a sharp narrow ridge 20 feet in height a few rods in the lee of a small drumlin. The ridge can not be traced over or around the drumlin, but what appears to be its continuation may be seen a few rods northwest of the drumlin's head. Farther southeast, in sec. 10, it follows the sags between the hills.

An esker south of the railway near Rubicon is in part strongly developed and in part scarcely traceable. It ends in a local kame deposit. Another esker northwest of Hartford is very slight and discontinuous.

LITHOLOGIC COMPOSITION OF ESKERS.

In order to determine the lithologic composition of the eskers as compared with the other glacial deposits pebbles were counted out and sorted at 23 different places and the percentages of the different constituents were noted. Of 400 pebbles from the eskers near Arlington and Morrisonville, Columbia County, 6¼ per cent was of crystalline rock foreign to southeastern Wisconsin; 86.5 per cent was of limestone, mostly Lower Magnesian; the rest was mostly of local chert with a little sandstone, shale, and quartzite. Of 900 pebbles from the eskers in the towns of Fountain, Otsego, and Westford, 6.5 per cent was of foreign crystalline rock; 83.3 per cent was of local limestone; the rest was mostly of local chert and sandstone with a little quartzite.

Estimate of the lithologic composition of the Waterloo esker based on examinations at two points shows 81 per cent of limestone from the Galena and Trenton, 6.5 per cent of sandstone, and 10 per cent of foreign crystallines, with a few quartzites and cherts, mostly of local derivation.

Estimate of the lithologic composition of the esker system in Watertown and Concord townships, Jefferson County, based on examinations at 4 exposures, showed that barely 6 per cent of the material is clearly foreign to the region, a few pebbles being quartzite and the rest crystallines. About 77 per cent is of limestone from the Galena and Trenton and about 15 per cent of Niagara dolomite with 2 or 3 per cent of sandstone and chert.

Examination of the esker gravels at 10 places in the towns of Hartford, Washington County, and Rubicon and Ashippun, Dodge County, gave crystalline rock from Canada, 9.9 per cent; sandstone and quartzite, probably from the Lake Superior region, 0.75 per cent; limestone, mostly Niagara, 88.2 per cent; chert, mostly from local limestone, 1.15 per cent.

Summing up these results it is seen that of the 4,000 or more pebbles examined from these esker gravels 8.5 per cent are foreign and are principally of crystalline rock from Canada. The remaining 91.5 per cent are mostly of limestone derived from the formations immediately underlying the deposits.

Comparison of these results with those of analyses of the ground moraine of the Green Bay Glacier (see p. 253) shows that there is very little difference, a fact that favors the interpretation that these gravels were derived from the drift in the lower part of the ice and were assorted and deposited by streams flowing at or near the base of the glacier in tunnels in or under the ice. The fact that the eskers are for the most part confined to valleys or relatively low tracts between the hills, and that the esker-forming streams appear to have been controlled in some measure by the configuration of the drift surface, indicates that the streams could not have flowed far above the base of the ice.

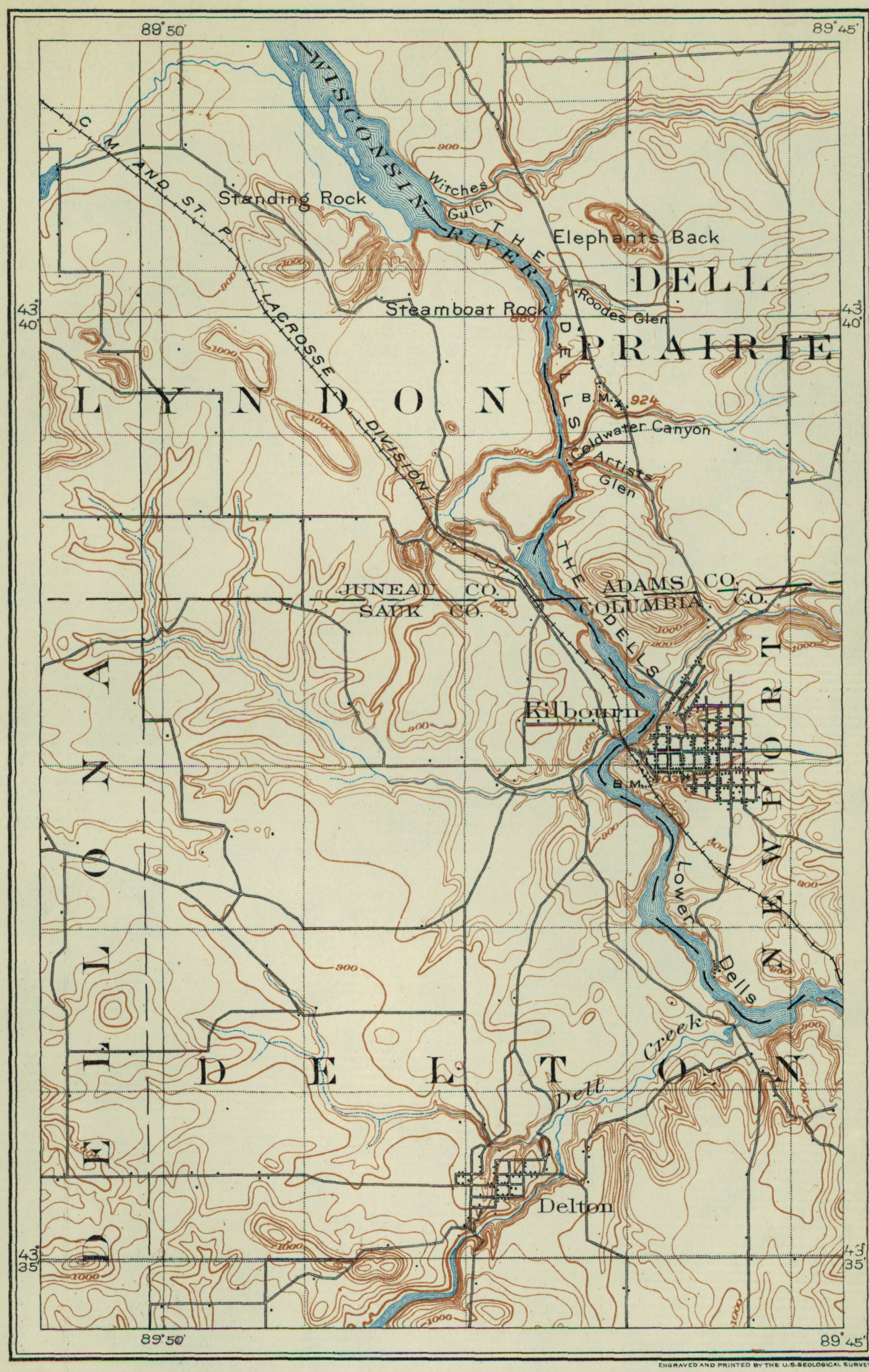
EXTRAMORAINAL DRAINAGE CONDITIONS.

The recession of the glacial front to the Lake Mills moraines caused many changes in the drainage. The waters ponded north of the Baraboo quartzite range were released and drawn off along the course now followed by Wisconsin River about the east end of the range. The discharge of such a volume of water must have been an event of considerable moment. With the lowering of the water to the east the channel across the Johnstown moraine south of Kilbourn must have been cut down rapidly and must have drawn down the level of the great glacial lake on the west.

A broad low ridge of sandstone surmounted by sandstone hills and traversed from east to west by the line between Juneau and Sauk counties and Adams and Columbia counties, extended westward from the preglacial valley of the Wisconsin in the vicinity of Kilbourn. (See Pl. II, in pocket.) The Johnstown moraine and bordering outwash terrace were deposited across the eastern part of this ridge, so that as Lake Wisconsin was lowered the last of the waters could escape only by cutting a channel through the sandstone. The lowest sag west of The Dells is that traversed by the railway 3 to 4 miles northwest of Kilbourn and is about 930 feet above sea level or about 90 feet above the river below the dam; so that the sag which finally located the stream must have been somewhat lower, probably 900 to 920 feet above sea level. East of the Johnstown moraine the river flows directly across its broad, ancient, buried valley through extensive marshes whose elevation is but little above 800 feet, so that there was a fall of 100 to 120 feet from the crest of the sandstone ridge to the lowlands on the east. With this fall and so friable a sandstone to work upon after the morainal drift dam south of Kilbourn had been cut through, the newly established Wisconsin River cut down very rapidly with no widening of its channel. The gorge thus eroded forms the picturesque Dalles, or Dells, of the Wisconsin, a gorge of wonderful beauty. (See Pls. V, *B*, p. 32, and XXXIII.)

The water ponded in the upper part of Dell Creek valley was drawn off across the sandstone ridge by the cutting of a gorge similar to The Dells and now occupied by Mirror Lake above Delton.

Simultaneously with the draining of glacial Lake Wisconsin, glacial Lake Baraboo was lowered, the stream flowing through the Lower Narrows and establishing Baraboo River in its present course. Water continued ponded in the basin east of Baraboo until the drift dam south of the Lower Narrows was trenched. So also that part of the lake held by the Johnstown moraine west of Baraboo must have continued somewhat longer, while the outlet was being cut through the drift dam. While this barrier was being eroded the stream above meandered over the lacustrine bed and formed the flood-plain terrace which is best developed near Kirkwood station, just west of the moraine and above North Freedom. The water in the upper part of the valley of Skillett Creek, being prevented by the moraine and outwash terrace from flowing eastward as formerly, turned northward over the ledges forming the falls and cut the picturesque glen known as the Pewits Nest and, joined by Pine Creek, made a third cut in sandstone to reach the newly established Baraboo. Seeley Creek, instead of following its former course through the broad valley south of this village, flowed eastward from the site of the Illinois mine through a narrow sandstone gorge. The waters in the upper Baraboo Valley and the Narrows Creek valley were drawn off through the gorges above Ableman. Near the upper railway bridge at Ableman Baraboo River is cutting in sandstone, though wells barely 80 rods distant have penetrated 90 to 100 feet or more of drift, showing that here the stream is out of its former course.



TOPOGRAPHIC MAP OF THE DELLS OF WISCONSIN RIVER AND VICINITY

Scale $\frac{1}{62,500}$

1 ½ 0 1 2 Miles

Contour interval 20 feet.

Datum is mean sea level.

1917 House Doc. No. ; 64th Cong., 2d Sess.

As far south as the Columbia-Dane county line the glacial waters flowed to Wisconsin River; beyond this point the drainage went to the Yahara, which was reestablished along the line of its former course as far as its junction with Rock River about 2 miles southwest of Fulton Center. From this junction to the bend north of Janesville the larger stream had already occupied the preglacial Yahara Valley. Basins behind drift dams filled with water, forming Lakes Mendota, Monona, Waubesa, and Kegonsa. The basin north of the Milton moraine was occupied by Lake Koshkonong, which probably extended over the surrounding lowlands until the cutting down of the morainal dams and rock sills lowered it to its present level. Silts deposited in this valley are exposed in the clay pits at the Fort Atkinson brickyards.

KETTLE INTERLOBATE MORAINE.

The part of the Kettle interlobate moraine which appears to the writer to be particularly associated with the Lake Mills morainic system and the correlated moraines of the Lake Michigan Glacier is the main or central ridge of the range of hills extending from the town of Genesee on the south to the town of Kewaskum, Washington County, on the north. This ridge varies in width from a fraction of a mile to something over 2 miles and at some points reaches a height of nearly 300 feet, so that it constitutes the most prominent topographic feature of this part of the State. The origin of this moraine is to be referred to the action of both the glaciers, it being a true interlobate moraine formed between the contiguous opposing fronts of the two ice sheets. On either side, lying closely parallel to and separated from the central ridge by narrow valleys or basins, or branching from the main ridge at low angles, are similar less bulky moraines which mark stages in the withdrawal of the respective ice fronts from the interlobate moraine. In places the distinction shown upon the map is more or less arbitrary, but for the most part the separation is clearly marked.

Through a large part of this extent the slopes of the interlobate moraine rise steeply from the valleys (and from the lakes which in several places occupy them) in prominent lines of bluffs 100 to 300 feet high. The surface of the ridge is generally marked by broad swells and bulky hills and in places is characterized by closely set knobs and kettles. Some of the kettles are 50 to 60 feet deep, but most of them are shallower. The hilly topography is best developed in the vicinity of Schleisingerville and Holy Hill and the pitted topography in the town of Barton (Tps. 11 and 12 N., R. 19 E.), east of Cedar Lake and south of Lake Nagawicka.

North of the village of North Lake the Kettle moraine is continuous, but southward from North Lake to Wales it is cut by several breaks which afforded outlets for waters from the glacier on the east across the moraine to the tributaries of Rock River. Two of the gaps are now occupied by Oconomowoc River and Bark River and a third by Scuppernong Creek. The gaps and the terraces leading through them are of importance in determining the relations of the two opposing ice fronts.

A few wells on lower parts of the moraine have reached bedrock at depths of 30 to 60 feet, but many others penetrate 100 to 200 feet of drift and show that the ridge as a whole is of drift. The average thickness of drift penetrated by 65 wells, most of which did not reach bedrock, is 129 feet.

Road cuts and gravel pits at intervals along the moraine give slight exposures of its structure and constituent material. One of the best of them is the railway gravel pit at Schleisingerville, which exposes 40 to 50 feet of drift consisting in part of stratified gravels, usually coarse, and in part very stony till. So far as can be judged from the records of wells collected, the greater part of the bulk of the ridge is sand and gravel, though at some points thicknesses of 100 feet or so of till have been found. Where the gravels occur they are generally covered by greater or less thicknesses of stony clay.

Estimates made at 13 different exposures along this moraine showed an average of 11.7 per cent of foreign material, of which all the stones excepting a few pieces of quartzite were igneous and metamorphic crystalline rocks from Canada. With the exception of a small percentage of sandstone and chert the remainder were limestones from the local formations of the region.

RECESSION OF THE DELAVAN LOBE.

CORRELATION OF THE MORAINES.

A series of slight terminal moraines marks the further deglaciation of the area traversed by the Delavan lobe and the main Lake Michigan Glacier. From Genesee Township (T. 6 N., R. 8 E.) northward to the vicinity of West Bend, Washington County, the Kettle interlobate moraine is bordered on the east by a belt of terminal-moraine deposits. These branch off at intervals and on being traced southward are found to merge with the broad Valparaiso morainic system, so that it appears that while the front of the Delavan lobe was withdrawing from one to another of these slight morainic belts the main west front of the Lake Michigan Glacier occupied the Valparaiso morainic system from Racine County southward. On the other hand, these slight morainal deposits appear to the writer, from their relations to the Kettle interlobate moraine, to be correlatives of the Lake Mills morainic system of the Green Bay Glacier. He is thus led to the opinion that the great Valparaiso morainic system, as mapped in Illinois and southern Wisconsin (with which are included perhaps the undifferentiated deposits of the Kalamazoo morainic system), is the correlative of all the moraines of the Delavan lobe and of the Johnstown, Milton, and Lake Mills moraines of the Green Bay Glacier. This seems to be substantiated by the fact that the Lake Border moraines which lie next inside (east of) the Valparaiso morainic system extend continuously northward into Ozaukee and Washington counties and seem to correlate best with moraines of the Green Bay Glacier that are later than the Lake Mills moraines.

It should be noted that the writer does not assert positive demonstration of most of the morainal correlations presented in this report. The complicated and indecisive relations and the poor development of the moraines at many places do not warrant any such claims. The correlations presented are those which appear to the writer as the result of his studies to be the most probable ones. To another worker in the same field things might look different in many places. It has been suggested that the proper correlation of some of the slight morainal deposits in northern Waukesha County is eastward instead of southward, thus correlating some of the Lake Border morainal deposits of the Lake Michigan Glacier with the Lake Mills moraines of the Green Bay Glacier and reducing the number of morainal belts to be correlated with the Valparaiso morainic systems. If the writer's correlations are correct the Valparaiso morainic system, as developed in Illinois and in southern Kenosha County, Wis., is the equivalent of all the morainal belts of the Delavan lobe. (See pp. 230–231.) That the Delavan lobe and the Green Bay Glacier were contemporaneous in the occupancy of their outer terminal moraines there can be no doubt, whence it appears that the front of the Lake Michigan Glacier occupied the Valparaiso morainic system at the same time that the Johnstown moraine was being formed by the Green Bay Glacier, and that it continued at this morainal belt in northeastern Illinois and southeastern Wisconsin until the front of the Green Bay Glacier had melted back from the last of the Lake Mills moraines. If, on the other hand, the Lake Mills moraines should be correlated with the Lake Border moraines the occupancy of the Valparaiso morainic system by the Lake Michigan Glacier would not be considered to have continued so long.

DISTRIBUTION OF THE DEPOSITS.

Of the slight morainal deposits so correlated one of the first lies just east of the interlobate moraine from the vicinity of Hartland southward to Wales. Farther south it passes near Genesee, Mukwonago, Caldwell Prairie, and Waterford, outlining the front of the waning Delavan lobe. At the latter place it joins the northward continuation of the Valparaiso morainic system. Between the morainal tract northwest of Waterford and Mukwonago two small deposits, lying, respectively, east and southeast of Lake Beulah station, may mark the position of the ice front. North of Mukwonago and west of the big marsh which lies in the Fox River valley the moraine is better defined. Waters discharging southward from the glacial front when occupying this position developed the gravel terrace north of the Mukwonago mill pond. Near Genesee the morainal topography is well marked, and thence northward to Wales there is a strong, pitted ridge, which, northward from the vicinity of Wales, to the head of Pewaukee Lake, has a strongly marked knob and kettle topography. From the latter place to the vicinity of Hartland the surface contours are of a gentle sag and swell type not everywhere distinguishable from the ground moraine.

The water from the glacial front about 6 miles south of the vicinity of Wales went southward and appears to have cut away some of the earlier deposits, so as to form the terrace on which stand the villages of North Prairie and Jericho Corners. It is thought that the development of this terrace by erosion may have been brought about by the opening of the Fox River valley south of Burlington, thus affording an outlet to the south for the glacial waters lower than the outlet at Genoa Junction. The pitted character of the terrace in Genesee Township (T. 6 N., R. 18 E.) indicates that at this time buried ice masses were still retained intact, otherwise the depressions would have been filled with gravel. Just north of the head of the terrace a narrow valley which cuts westward through the Kettle moraine and which was once an outlet for glacial waters is traversed by the Chicago & Northwestern Railway. On the north side the two moraines coalesce, only to be again separated 1 and 2 miles farther north by a narrow terrace, in which heads the valley now occupied by the headwaters of Scuppernong Creek. This valley, where it cuts through the Kettle moraine just south of Government Hill, is bordered by slight traces of a terrace corresponding in elevation with that in which the valley heads. Evidently here also was an outlet for water from the Lake Michigan Glacier. The relations of these outlets confirm the conclusion drawn from studying the area to the south that the Green Bay Glacier had been melted back at least as far as the vicinity of Dousman by the time of the retreat of the ice front on the east to the moraine in Genesee Township.

Between the head of Pewaukee Lake, the south end of Lake Nagawicka and the bordering moraines is another terrace leading through an outlet to the basin of the latter lake. This break in the Kettle moraine is now traversed by the electric railway. A much more extensive gravel terrace borders Bark River from the east side of this basin northward to and beyond the vicinity of Merton and declines gradually toward the lake. In order that the outlet for the waters forming these terraces might be open, the front of the Green Bay Glacier must have been melted back beyond the line of Bark River. Probably it stood at the first of the Lake Mills moraines, and the junction of the two ice fronts must have been somewhere in the vicinity of Beaver and Pine lakes.

The ill-defined deposits marking the next position of the Lake Michigan glacial front extend from the vicinity of Waterford northward to a point one-half mile east of the village of Chamberlin. Depressions associated with them now form the basins of Tischigan, Ministers, Long, and Denoon lakes. Between these and the bed of Fox River in Vernon Township (T. 5 N., R. 19 E.) is an outwash gravel terrace of about 2 square miles on which stand the villages of Big Bend and Chamberlin. From this vicinity the morainal deposits may be traced northwestward across the upland tract to and across the Fox River valley, which they partly block in southwestern Waukesha Township (T. 6 N., R. 19 E.). These deposits define the front of what was left of the Delavan lobe. The morainal topography is most strongly marked east of Vernon station and between the Wisconsin Central Railway and Fox River. In the valley the moraine is bordered by an outwash terrace. East of Mukwonago the glacial waters escaped down Fox River. Between Mukwonago and the moraine in Waukesha Township a temporary lake must have been held in the valley, where is now a big marsh, until the discharge cut through the drift barrier about a mile northeast of Mukwonago and opened the narrow channel through which Fox River flows. In Pewaukee Township (T. 7 N., R. 19 E.) slight morainal deposits not far from the line of the electric railway extend the line to Pewaukee Lake, north of which they merge with those described above.

Two rather discontinuous belts of poorly developed sag and swell deposits mark the northward continuation of the Valparaiso morainic system from the vicinity of Little Muskego Lake to Waukesha, but are insufficient in amount to greatly obscure the drumloidal trend of the ground-moraine topography which they overlie. One of these belts just east of Waukesha is continuous and well developed from the stone quarries north of Waukesha to Pewaukee. Beyond Pewaukee it is traceable by rather indefinite deposits to the broad morainal tracts north of the railway in the towns of Lisbon and Richfield (Tps. 8 and

9 N., R. 19 E.). While the ice front stood at the line marked by these deposits the gravel terrace on which the city of Waukesha now stands was formed by the glacial waters. A similar terrace was formed in a small valley in the southern part of Waukesha Township. The other belt, which lies a mile or so farther east, is indefinite and discontinuous, until it merges with the broad morainal tract north of Sussex and Templeton. These morainal belts consist generally of low ridges or irregular deposits of gravelly drift with surfaces characterized by sags and swells and in places by knolls and sharply depressed kettle holes.

Extending northward from the vicinity of Merton, Sussex, and Templeton into T. 10 N., R. 19 E. (Polk Township), where it begins to coalesce with the interlobate moraine in the tract between Schleisingerville and Cedar Creek, is a morainal deposit 3 to 9 miles wide. This deposit can not be separated into distinct morainal belts like those to the south but apparently represents continuous deposition during the same stages of the retreat. Through much of this tract the drift is very thick. Reliefs of 100 to 200 feet or more occur, and none of the wells are known to reach bedrock, though several range in depth from 200 to 315 feet. These wells are largely in sand and gravel below a coating of clay or till. Some show considerable thicknesses of "hardpan," which may represent an earlier drift of sheet or sheets. It is quite possible, if not probable, that a continuation of the buried preglacial valley traced farther southwest extends northeastward beneath these deposits in Richfield and Polk townships. (See Pl. II, in pocket.)

In adjacent parts of the towns of Erin, Richfield, Merton, and Lisbon there are extensive terraces bordering Oconomowoc and Bark rivers and leading to the basins of North and Nagawicka lakes. These separate and surround several morainal tracts, so that the relations are not altogether clear. Their surfaces are nearly flat, except for numerous kettle-like pits, and decline gently toward the southwest, indicating that glacial waters flowed in that direction. Exposures show water-laid gravels beneath a thin coating of loamy clay. A large depression, where lay a buried ice block, is now occupied by Lake Keesus and the adjacent marsh. The basins of Okauchee, Mouse, North, Pine, Nagawicka, and Beaver lakes must also have been occupied by ice blocks when the terrace was formed, otherwise they would have been filled by gravels. In these terraces are now cut the valleys of Oconomowoc and Bark rivers. The Oconomowoc deepens northward with the rising terrace from about 20 feet to about 80 feet. The bank ranges in depth from about 20 feet to about 60 feet.

Narrow remnants of a second and lower terrace, on which stands North Lake village, border Oconomowoc River from the bend north of the village of Stone Bank to about a mile north of Monches. Similar remnants border Bark River, three-fourths mile southwest of Bark Lake, 1 mile west of Colgate, and from the vicinity of Lake Five, a mile west of Merton. These terraces appear to be partly the result of direct deposition as outwash by glacial waters and in part to have been developed by erosion of the waters broadening the outlets. The terrace on which stands the village of Hartland was probably formed while the Lake Michigan Glacier occupied the moraine on the east and while the front of the Green Bay Glacier stood at the first of the Lake Mills moraines. As the ice on the east melted, the Hartland terrace was extended northward to a position 2 miles or more northeast of Merton. At the same time the front of the Green Bay Glacier melted back to the moraine north of Oconomowoc, and the terrace north of Okauchee Lake was formed and extended northeastward across the ice block buried on the site of the basin of North Lake, and thence to the vicinity of Lakes Keesus and Monches.

Continued melting of the Lake Michigan Glacier moved its front back to the vicinity of Lows Lake, Lake Five, and Bark Lake, and the waters began to erode the previously formed terrace and to develop the second terrace. By the time the second terrace was formed the front of the Green Bay Glacier must have melted back to or near the position of the moraine just east of Hartford. There are some indications also that from the vicinity of Templeton and Lannon southward the Lake Michigan Glacier may by this time have abandoned the Valparaiso morainic system and the last of the moraines of the Delavan lobe which are its northward continuations. Some slight intermediate morainal deposits in the town of

Menominee suggest a connection with the west ridge of the Lake Border morainic system.

A pitted terrace of 1 to 2 square miles extends from 1¼ miles south of Ackerville to Oconomowoc River north of Freis Lake in T. 9 N., R. 19 E. (Richfield Township). This separates two parts of the morainal tract.

Numerous basins in or between these moraines held small lakes. Some of these have been drained, others have been overgrown by vegetation and transformed into marshes or tamarack swamps, and others still contain ponded water. The laminated clays used for manufacturing brick at Schleisingerville were deposited as silt in such a basin.

LITHOLOGIC COMPOSITION OF VALPARAISO MORAINIC SYSTEM AND ASSOCIATED DEPOSITS.

Estimates of the lithologic composition of the gravels of the Valparaiso morainic system and of the correlated later moraines of the Delavan lobe were made at 39 places from the Illinois State line northward to Polk Township, Washington County. Of the 5,000 or more pebbles examined 12.24 per cent were of rock foreign to this part of southeastern Wisconsin. This included 11.54 per cent of crystalline rock from Canada, most of the other foreign material being sandstone and quartzite from the Lake Superior region. Local sources probably supplied 87.7 per cent, most of it from the Niagara dolomite, a little from the limestones of the Milwaukee and Waubakee formations, and possibly some from the "Cincinnati" shale and Trenton limestone. As in the Kettle interlobate moraine so also here the percentage of foreign material is a little higher than that in the drift of the Green Bay Glacier.

One of the most notable features of these deposits is the abundance of bowlders scattered over the adjacent parts of the towns of New Berlin, Muskego, Waukesha, and Vernon (Tps. 5 and 6 N., Rs. 19 and 20 E.). These bowlders have been very largely collected from the fields and piled along the fences, in some parts forming numerous walls 3 feet or more in height. In a certain pasture lot about a mile west of Little Muskego Lake, where the bowlders appeared to be as originally deposited, neither having been collected nor having received additions from the adjacent fields, the writer counted 4,200 in about 1¾ acres. It was quite possible to cross the field by stepping from one stone to another. Of these bowlders less than 1 per cent were of other than foreign crystalline rock.

As the bowlders lie upon the surface of the drift and are almost all of distant derivation it seems probable that they were transported as englacial drift embedded in the ice above the zone of basal accumulation. There is a striking contrast between the very small percentage of local rock among these bowlders and the high percentage of local material in the body of the drift, which was probably very largely accumulated and transported at the base of the ice.

ESKERS.

Five small eskers mark positions of subglacial streams in the part of the area of the Lake Michigan Glacier thus far described. One lies about a mile southwest of Caldwell Prairie; one about 4 miles west of Burlington, and another about 4 miles west of Genoa Junction. The last is about a mile in length, 10 to 20 rods in width, and 5 to 10 feet in height. A fourth in sec. 36, T. 6 N., R. 19 E. (Waukesha Township), 4 miles north of Big Bend, consists of a slight gravel ridge only a few rods long. A fifth, in secs. 21 and 22, cut through by the Wisconsin Central Railway, about 3 miles south of Waukesha, though of slight relief, is interesting because its bedding dips westward, indicating that the flow of the winding stream which formed it was in that direction (up the hill slope). The fact that about 86 per cent of the gravel is of local derivation seems to indicate that the stream flowed at or near the base of the glacier, where it handled subglacial drift.

LATER RECESSION OF THE GREEN BAY GLACIER.

MORAINAL DEPOSITS.

Within the borders of the Lake Mills morainic system throughout a large crescentic area 10 to 12 miles wide on the east and west and 20 to 30 miles wide on the south, no marginal morainal deposits left by the melting Green Bay Glacier have been observed. North and east, within the curve of this crescentic ground-moraine tract, four other belts of slight morainal deposits, similar in character to the members of the Lake Mills morainic system, have been traced. These have their correlatives in the Lake Border moraines of the Lake Michigan Glacier and mark positions of halt of the ice front, probably after readvances, which interrupted the general progress of deglaciation of the area under discussion.

For convenience of reference these may be designated, in order from the outer to the inner, as the Green Lake, Waupun, Rush Lake, and St. Anna moraines.

GREEN LAKE MORAINE.

In the towns of Kewaskum and Barton (Tps. 11 and 12 N., R. 19 E.) a moraine extends westward from the vicinity of the interlobate moraine. From the point of divergence northward for 15 to 20 miles the position of the ice front as shown by the morainal deposits was parallel to the interlobate moraine and separated therefrom by a valley, mostly less than a mile in width. The interlobate angle at this stage appears to have been moved northward nearly to Glenbeulah in T. 15 N., R. 20 E. (Greenbush Township), Sheboygan County.

Two or three miles south of Greenbush, in the midst of the great morainal tract, a pitted terrace with abrupt margins slopes gently southwestward, as if formed by water discharging from the interglacial angle to the head of the interlobate valley, principally from the Lake Michigan ice front. The abrupt marginal slopes and channels are due to partial erosion by the glacial waters after deposition of the gravels ceased.

The small valley heading at the west margin of this terrace, now drained by Milwaukee River, marks the separation of the Green Lake moraine from the interlobate moraine.

From the interlobate angle south of Glenbeulah, southward to Dundee on the west side of Long Lake, the surface of the moraine is exceedingly irregular. Being very largely unfit for cultivation, it still remains wooded. Here may be seen terminal-moraine topography in its most characteristic development. (See Pl. XXXIV, *A*.) Extending from the SE. ¼ sec. 20, Greenbush Township, southwestward through the dry bed of Bear Lake in sec. 29 and the NW. ¼ sec. 32, is an esker marking a line of subglacial drainage which discharged to the interlobate valley.

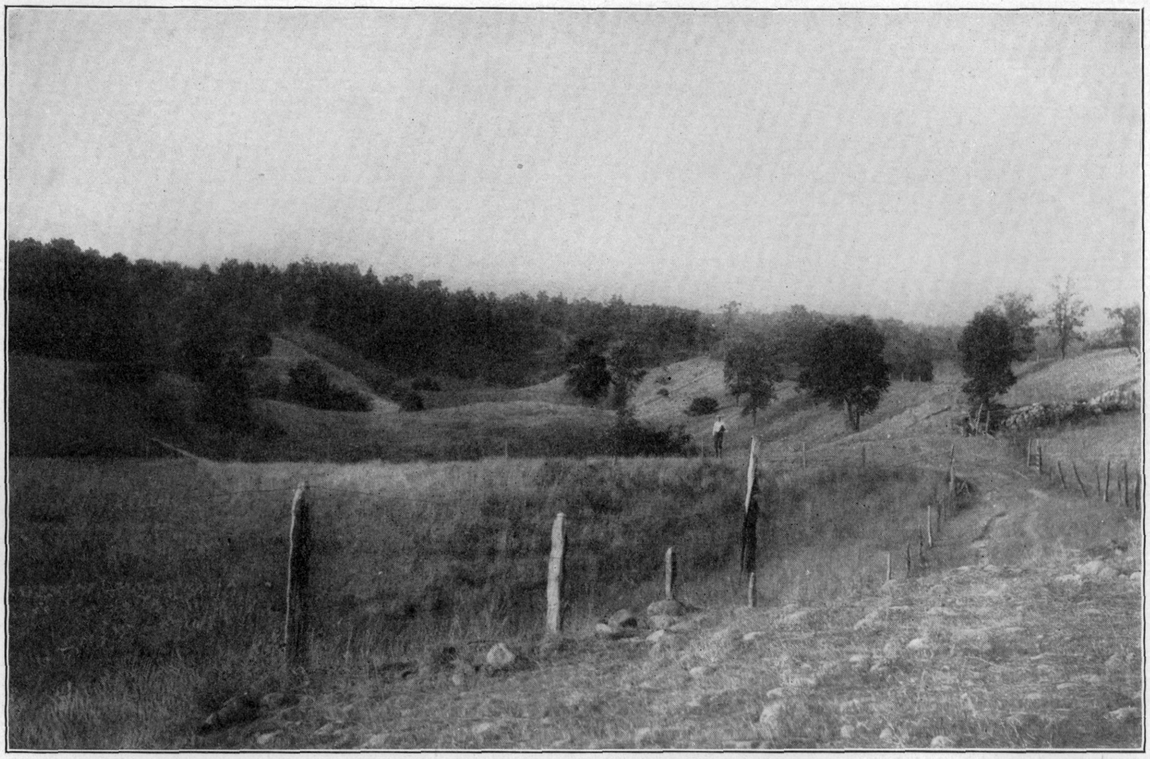
In this part north of Dundee the moraine is very bulky and probably indicates deposition long continued after the ice front had begun to melt back from the part of the moraine lying farther south. This seems true, particularly because back (west) of this moraine interspersed morainal deposits, tamarack swamps, and lakes extend westward for several miles to Waucousta and Newcassell. Owing to the great irregularity of the morainal deposits and the interlacing swamps which occupy the lower unfilled tracts the topography throughout this broad area is very peculiar, probably resulting from marginal deposition continued as the glacial front slowly retired or the ice disintegrated in place.

Near Dundee the front of the moraine is a sharp narrow esker-like ridge with kame and kettle topography behind it (on the west). Through the next 8 miles, from the vicinity of Dundee southward past the village of Jersey, the moraine ranges from a sharp, narrow ridge to a belt a mile wide. Through much of this distance it is bordered on the east and west by tamarack swamps, from which marginal slopes rise abruptly. The east front is especially sharp and regular, rising as a bluff 50 to 60 feet high. In part the top is broad and flat, like a pitted terrace; elsewhere it is marked by kames and kettle holes. The constituent material so far as exposed is stratified well-rounded gravel.

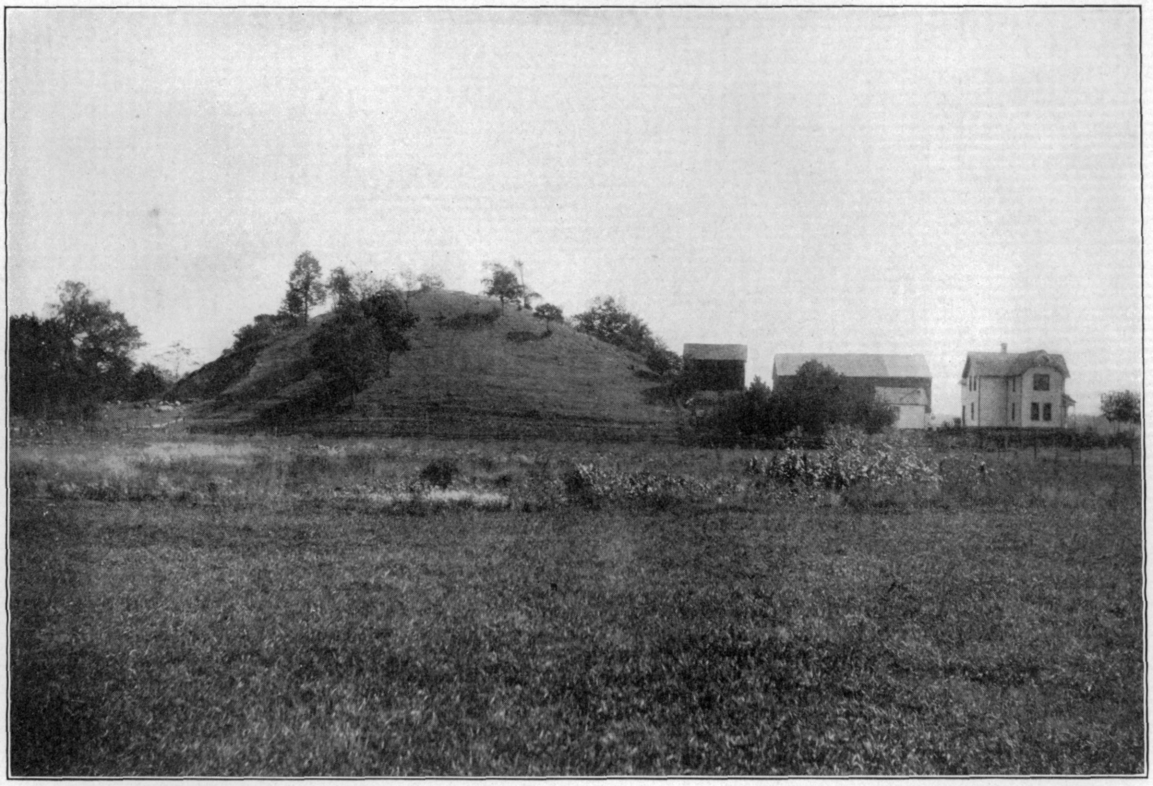
Along the road at the north end of the swamp a mile west of Jersey village an esker 10 to 30 feet in height marks the position of a stream which flowed in an ice channel and discharged into the interlobate valley at the ice front. To outwash by this and other similar glacial streams was probably due the deposition of the broad gravel terrace which, for a mile north of the road leading west from Jersey, extends completely across the interlobate valley.

From the southern part of T. 13 N., R. 19 E. (Auburn Township), southward to Milwaukee River near Kewaskum the moraine is characterized by large and small detached kames of typical form, rising from a gently undulating area. (See Pl. XXXIV, *B*.) Some of these kames are 100 feet or more in height. They are composed of sand and gravel and, in some excavations, show finely assorted and stratified drift.

Receding from this moraine the ice front formed the moraine-like belt which extends northwestward from the vicinity of Kewaskum for about 12 miles into southeastern Byron Township (T. 14 N., R. 17 E.). The present stream which drains most of Ashford Township



A. TERMINAL-MORAINE TOPOGRAPHY 2 MILES SOUTH OF GREENBUSH, SHEBOYGAN COUNTY, WIS.



B. KAME, KEWASKUM, DODGE COUNTY, WIS.

(T. 13 N., R. 18 E.) nearly coincides in position and direction of flow with this deposit. The peculiarity of this belt is its trend, which, like that of an esker, is parallel to the direction of the ice movement, as shown by striæ observed at Elmore, and is nearly normal to what must have been the position of the glacial margin when it was formed. It is, in fact, partly terminal moraine but largely a kame-esker belt formed by glacial drainage during continued recession of the ice front from the moraine at Kewaskum. Much of its topography is of the kame and kettle type. In sec. 31, T. 13 N., R. 19 E. (Auburn Township), an esker winds through the moraine deposit which was formed when the ice front stood a mile or so northwest of Kewaskum. West of the railway and 2 to 3 miles south of Campbellsport a pitted gravel terrace with an abrupt east margin and an irregular high-pitted ice-contact west margin lies about 980 feet above sea level and was probably formed as a delta by a glacial stream discharging from the ice front into waters ponded in the Milwaukee River valley. One well on this terrace penetrated 115 feet of sand. On further recession of the ice the morainal deposits northeast of New Cassel and in the vicinity of Elmore were laid down. With these are also to be correlated patches of gravels in Wayne and Theresa townships. Mild morainal topography continues northwestward past Elmore, and an interrupted esker extends through sec. 1 and the NE. ¼ sec. 12, T. 13 N., R. 17 E. (Lomira Township).

South of Kewaskum on the west side of Milwaukee River is a bold, bulky ridge nearly 200 feet in height. North of Cedar Lake kame and kettle topography is very strongly developed. In southwestern Barton Township the Green Lake moraine swings sharply westward and for a few miles trends northwestward. The moraine narrows toward the west and its margins become less well defined. In Tps. 11 and 12 N., R. 17 E. (Herman and Theresa townships), the moraine is for the most part a slight ridge 10 to 80 rods in width, composed of a confused mass of till, gravel, and bowlders, with its surface abundantly strewn with crystalline bowlders. The smallness of the deposit indicates a comparatively short halt of the ice front at this position. At several of the exposures the percentage of foreign material is much above the average; two estimates showed that 23 and 25 per cent of the stones were crystallines.

One of the most interesting features of this moraine is its relation to the drumlins in the town of Theresa, where the small ridge runs transversely to the drumlin trend and indiscriminately over both drumlins and intervening ground-moraine tracts, showing clearly that its deposition was the later.

In a distance of 5 miles the surface on which this deposit was made ranges in elevation from 920 to 1,100 feet above sea level. A portion of this part of the moraine is described and illustrated by Chamberlin.[1]

From the northwestern part of the town of Herman the moraine is traceable westward through sec. 1, T. 11 N., R. 16 E. (Hubbard Township). As it nears the Niagara escarpment the ridge curves northward for about one-fourth mile and then turns slightly southward at the crest of the bluff. From the foot of the bluff, 150 feet below, the deposits extend across the railroad and envelop the head of a large drumlin to the west. Beyond a small intermediate patch the morainal deposits reappear over an irregular area in and about the village of Horicon and form the drift dam at the foot of the great Horicon Marsh. The large drumlin at the east edge of the village is surrounded by these deposits, which are pitted with kettle holes and are interspersed here and there with depressions with abrupt gravelly marginal slopes occupied by marshes and tamarack swamps. Stratified gravels are exposed in several excavations in this deposit, and numerous wells show thicknesses of 20 to 60 feet of drift. As the Neosho esker is traceable northwestward to connection with this deposit it is probable that the debouchure of the Neosho esker-forming stream moved northwestward along the stream course with the recession of the ice front and that a part, at least, of the gravels are to be correlated with the stage at which this esker was formed.

For about 4 miles westward to the vicinity of Rolling Prairie the position of the moraine is not very clear. There is some indication that a reentrant in the ice front carried the margin northward to the vicinity of Burnett Junction. Either this was the case or else the moraine-like belt of topography which extends southward from just west of Burnett Junction and thence

[1] Geology of Wisconsin, vol. 2, pp. 215-216, fig. 8, 1907.

southwestward to the northwestern part of T. 11 N., R. 15 E. (Oak Grove Township), was a line of kame-esker deposition, marking the course of a shifting stream which discharged at the ice front. The topography of this belt, however, resembles that of a moraine rather than that of an esker. Knob and kettle topography is particularly well developed on the Spring Brook farm southwest of Burnett. One abrupt isolated hill in the SE. ¼ sec. 29, T. 12 N., R. 15 E. (Burnett Township) was used as a triangulation station in a former survey. A pit in this hill shows it to be composed of coarse morainal gravels and till. About 13 per cent of the gravels here exposed are of whitish crystalline limestone resembling the Niagara dolomite and suggest that this particular isolated hill, instead of belonging to the moraine under discussion, is really a remnant of a deposit formed during an earlier advance by an ice sheet which was moving in a more westerly or southwesterly direction and bringing material from the Niagara formation, whose nearest remnant is 7 or 8 miles to the east.

East of Beaver Dam these morainal deposits are spread over an area of 6 or 8 square miles, parts of which show strongly marked kame and kettle topography. From this locality the trend of the glacial margin shifted to northwest. Deposits of this stage occur just east of the lake in the north part of Beaver Dam Township and northward along the road just west of Fox Lake. The depth of drift penetrated by wells in this part indicates that the basin of Fox Lake is due to the damming of the head of a preglacial valley. Beyond the big marsh that occupies part of this valley, on the narrow crest of the moraine, the belt of deposits may be traced upon the upland to the head of the next reentrant in the margin at Lake Emily. This beautiful lakelet is cut off from the marsh which occupies the valley to the west by a fine morainal dam about 80 rods in width. Beyond the upland north of this valley the moraine drops down to the lowland of the Lower Magnesian limestone north of Lake Maria and spreads out more broadly. Here it probably completed the blocking of the depression and inclosed the lake basin.

In the valley of Grand River the ice front swung westward to the vicinity of Manchester. The valley appears to have been occupied by a stream discharging at the ice front, fragments of a well-formed esker lying half a mile south of the village and also 2 miles farther east. Their connections were not traced in detail For 2 miles west of the village the valley is occupied by a great deposit of gravels in the form of an irregular, discontinuous, much pitted terrace. The material exposed is sand and well rounded 1 to 3 inch gravel. Parts of the deposit resemble a delta of an esker-forming stream that discharged into standing water at the ice front. The exact elevation of the surface of the gravel deposit is not known, but aneroid readings indicate that it may not have been much, if any, higher than the waters ponded along Fox River and its tributaries at this stage of glaciation and discharging to Wisconsin River at Portage.

On the upland north of the Grand River valley the moraine dwindles to a narrow esker-like marginal ridge until the town of Marquette is reached. Thence northward across the broad trough between Green and Puckaway lakes the moraine is finely developed, with an average width of about a mile.[1] Here it forms the drift dam inclosing Green Lake basin on the west, and from this fact the name Green Lake moraine is proposed for the whole belt as here described from the interlobate moraine in Washington County westward and northwestward. The soundings of Green Lake show a depth of nearly 300 feet, and the highest part of the crest of the moraine rises about 120 feet or more above the water level. It has been noted also that the well at the Chicago Club house on the north shore of Lake Puckaway about 7 miles west of the moraine shows that the preglacial trough at that place extends more than 330 feet below the level of the surface of this lake and considerably more below that of the higher parts of this moraine. It is not known that the whole bulk of this fill in the preglacial trough was deposited at this time of moraine formation, but it was certainly completed at this stage and the history of Green Lake in its present condition dates from the melting of the ice away from this moraine and from the lake basin.

While the ice front stood at the Green Lake moraine, it was bordered on the east by a lake, formed by waters ponded in the Fox River valley, that discharged westward to Wisconsin River at Portage. Into this lake was probably

[1] See Neshkoro topographic map.

discharged silt-bearing water from the morainal front, adding more or less lacustrine clay to the earlier filling of the valley to the west.

North of this trough the ice margin lay across the Lower Magnesian limestone ridge. On the ridge morainal deposits were not noted (they were not sought for carefully), but on the lowlands to the north they extend northward across the railway, ending in a 100-foot ridge within the bend of Fox River in the southern part of T. 17 N., R. 12 E. (Seneca Township), east and north of the abandoned site of Hamilton.

For some distance north of Fox River the moraine can not be traced very definitely, but there are some indications that the ice front extended northwestward almost to Neshkoro. Thence northward through Waushara County it is probably represented by a considerable development of morainal and terrace deposits.

At no place throughout its mapped extent is the Green Lake moraine bordered by terraces of outwash sand and gravel except in the vicinity of Manchester, where it is probable that an esker stream discharged at the ice front northwest of Neshkoro in southern Waushara County. In the Fox and Grand river basins the ice front was evidently bordered by a lake discharging to Wisconsin River at Portage.

The clay used in brickmaking one-half mile southeast of Neshkoro is composed of silts deposited in the ponded waters at this or a somewhat earlier stage. Doubtless extensive deposits of laminated clay occur in the low tracts beneath the marsh deposits.

Besides the eskers described in connection with the morainal deposits (pp. 294–295) there are, in Theresa and Wayne townships, two small eskers that indicate the positions of subglacial streams. Another esker, extending southeastward 1½ miles through the tamarack swamp in secs. 9, 15, and 16, T. 14 N., R. 19 E. (Osceola Township), marks the location of a stream discharging at the ice front when it had receded perhaps about 2 miles from the morainal front west of Long Lake.

WAUPUN MORAINE.

The next position of halt of the ice front is marked by a discontinuous line of deposits that varies in character and degree of development, and that in few places forms a strong moraine of the ridge type. At the time of its formation the fronts of the two glaciers still diverged south of Greenbush and Glenbeulah, so that additions continued to be made to the great accumulation of drift in that tract. Three miles southwest of Greenbush, near the middle of sec. 20, T. 15 N., R. 20 E., the ice front diverged from the interlobate tract. For 5 miles southwestward from this point to the northeastern part of T. 14 N., R. 19 E. (Osceola Township), the position of the glacial margin is marked by an abrupt knolled and pitted ice-contact slope about 60 feet in height, from the crest of which a nearly flat terrace, somewhat pitted with ice-block depressions, slopes gradually southward to the foot of the inner face of the big Green Lake moraine. This terrace has an area of nearly 4 square miles, and contrasts markedly with the big moraine on the southeast, against which the gravels were washed by the outflow of glacial waters. Some morainal patches occur in secs. 4, 5, 8, and 9, Osceola Township. From the SW. ¼ sec. 17 a narrow morainal belt extends westward nearly 5 miles to the railway in the middle of Eden Township (T. 14 N., R. 18 E.). Through part of this belt kame and kettle topography is strongly developed. Particularly notable is a sharp esker-like ridge which forms part of the deposit in secs. 23 and 24, Eden Township. South of this moraine and extending to the vicinity of the village of Waucousta is a somewhat interrupted, pitted gravel plain, which must have been formed by glacial outwash at about this same time.

In southwestern Eden Township, and thence westward through the towns of Byron and Lomira, the position of the glacial front is scarcely traceable, though it may be represented by slight patches of gravels north of Thetis station (Brownsville post office) and south and southeast of Byron.

In the southeastern part of the town of Oakfield, Fond du Lac County, a narrow morainal ridge extends westward through the north halves of secs. 26 and 27 to the crest of the Niagara escarpment at the Mapleton stock farm. On the lower land to the west morainal deposits occur south of the railway west to Oak Center. At the head of the Horicon Marsh, in sec. 33, morainal deposits merge into a pitted gravel terrace which is bordered by abrupt marginal slopes and has the aspect of a delta deposit formed in the lake which occupied the basin to the south. The terrace is cut through by a sharp, narrow valley.

Between the head of Horicon Marsh and the vicinity of Ripon there are considerable tracts of morainal deposits which belong to this moraine. They are, however, so irregular and discontinuous and their boundaries are so very indefinite that only after they had been sketched on the map could they be correlated into anything like a definite moraine.

North of Waupun the deposits spread over an area of 6 or 8 square miles, marked by a topography of gentle sags and swells, with numerous included marsh depressions and some sharper kame topography. Two narrow belts of similar topography, which join the larger tract from the northeast, though not well-defined eskers, may mark lines of shifting streams that deposited gravels beneath the ice and discharged at the ice front to the head-waters of Rock River, which at this stage had nearly reached its maximum extension as a result of the recurring recessions of the glacial front. Similar morainal deposits are spread widely over the northeastern part of the towns of Alto and Metomen (Tps. 14 and 15 N., R. 14 E.). There is some indication that the belt divides, the outer line passing northward near the west line of Metomen with a definitely ridged crest and thence probably swinging westward as the ice margin dropped over the margin of the upland to a lobe lying in the basin of Green Lake. North of the lake there is a small patch of morainal deposits in the northwestern part of Dartford, but beyond this point the writer has found no trace of them.

Deposits of an inner belt are present west of the railway northward into the town of Ripon (T. 16 N., R. 14 E.) and are strongly marked in the valley north of Arcade, where the kame and kettle topography merges with a pitted terrace on the west. No continuation of these deposits was found northward over the upland to the Fox River valley. It is possible that the drift ridge in the western part of Berlin is to be correlated with this moraine. At some of the exposures of this morainal belt fully 99 per cent of the gravel is of local limestone, foreign crystalline rocks being present only in very small amounts.

RUSH LAKE MORAINE.

A third position of the ice front a short distance within the last noted is marked by very similar phenomena. Three miles southwest of Greenbush a second and lower, flat, pitted, gravel terrace extends from the foot of the first ice-contact slope northward about a mile to a second abrupt margin whence the surface drops down to the marsh through which flows Mullet Creek. A well on this second terrace penetrated 100 feet of gravel. Farther southwest through northwestern Osceola and northern Eden townships (T. 14 N., Rs. 19 and 18 E.) there are small patches of morainal gravels, associated terraces, and eskers near the road between Eden and Mitchell.

No trace of this moraine has been noted in Byron Township (T. 14 N., R. 7 E.) except a small patch of morainal deposits north of Byron post office. Just west of Oakfield there is a gravel terrace which may have been formed at this stage. In the northwestern part of T. 14 N., R. 16 E. (Oakfield Township) and thence northwestward through Springvale Township indefinite patches of morainal deposits are marked by gentle sag and swell topography and are bordered, in adjacent parts of secs. 9 and 16, by a pitted gravel terrace. In the southwestern part of Rosendale the moraine becomes more marked and may be traced thence northwestward through the town of Ripon (T. 16 N., R. 14 E.) as a fairly definite belt. Two miles east of Ripon kame topography is strongly developed. The deposits lie across the margin of the upland near the southwest corner of sec. 3 and across the preglacial valley as a morainal dam inclosing the south end of the basin of Rush Lake (whence the name of the moraine).[1] Kame topography is developed along the railway, and to the west a flat terrace slopes gently westward to the marsh and is probably underlain by outwash gravels deposited by the glacial waters which escaped thence southwestward to the waters ponded in the Green Lake and Fox River valleys. From a mile south of Rush Lake station northward the moraine is represented only by slight patches.

North of the line of the Rush Lake moraine there are small morainal patches and belts in Empire and Forest townships (T. 15 N., Rs. 18 and 19 E.) and near St. Cloud. A glacial stream discharging at the ice front deposited the gravels forming the esker, which is traceable, with numerous breaks, southward from $1\frac{1}{4}$ miles east of St. Anna to Sheboygan Swamp.

[1] See Ripon topographic map.

About the time that these were deposited the formation of the morainal deposits which cover so large a part of the northwestern half of Schleswig, Eaton, and western Liberty townships, Manitowoc County, began.

A few similarly situated small patches of morainal deposits occur farther west in T. 16 N., R. 15 E. (Rosendale Township), and T. 17 N., R. 14 E. (Nepeuskun Township).

South of the railway, near the west line of the town of Rosendale, a stream must have discharged from its channel in or beneath the ice, for a well-defined sinuous gravel ridge, or esker, extends from the SE. ¼ sec. 18, southward through sec. 19, where it borders the east side of the road for nearly a mile. South of the railway in the NW. ¼ sec. 30 it becomes fragmentary as it swings westward toward the moraine. An estimate of the gravels exposed in a road cut showed 97 per cent to be limestone pebbles from the Galena and Trenton.

ST. ANNA MORAINE.

The St. Anna moraine, which marks the completion of the next stage in the recession of the front of the Green Bay Glacier is characterized by morainal deposit more definite than those of the Rush Lake moraine. During this stage the interlobate angle between the diverging fronts of the two glaciers was shifted somewhat east of north into Manitowoc County beyond the limits of the area under discussion. The exact position of this angle is not known, for the deposits were later overridden and obscured by a readvance of the glacier and the deposition of the red till.

In the southern half of Eaton Township (T. 18 N., R. 21 E.) a great morainal deposit 3 to 4 miles in width and marked in part by strong kame and kettle topography is bordered by a low tract on the east and west. From the tamarack swamp in secs. 19, 20, and 30, steep slopes rise more than 100 feet to the crests of the bulky drift hills. The topography and extent of this deposit suggest that it may be part of the interlobate moraine. The position of the front of the Green Bay Glacier is marked by the moraine which extends southwestward from Eaton Township, through western Schleswig north of Kiel, southern New Holstein near St. Anna, Marshfield, and Taycheedah townships and thence southward along the Niagara escarpment in Empire Township (T. 15 N., R. 18 E.). There is no indication that the ice reached the upland in Byron Township (T. 14 N., R. 17 E.) at this stage.

The southern part of Eaton Township and the northwest half of Schleswig Township (T. 17 N., R. 21 E.), are very largely characterized by terminal moraine, whose deposition was probably completed at this time by the Green Bay Glacier. One of the most striking features of this tract is the elongated depression extending southward from Steinthal. This has a flat swampy bottom, ranging in width from a few rods to one-half mile, from which abrupt ice-contact slopes rise 40 to 100 feet or more to the surrounding morainal surface on either side. It is not a depression due to erosion but is a fosse resulting from the burial and subsequent melting of an elongated mass of ice. It is bordered on the east by what resembles a pitted terrace and on the west by an abrupt morainal crest. Three miles north of Rockville, in the NE. ¼ NE. ¼ sec. 8, Schleswig Township, at the top of the west slope of this depression a well penetrated 105 feet of sand and 10 feet of hardpan lying in Niagara dolomite.

A few rods down the slope to the east another well penetrated 75 feet of sand and 73 feet of hardpan overlying gravel without reaching rock. Probably the sand represents the morrainal deposits of this stage and the underlying "hardpan" is the till of the earlier ground moraine. Other wells on the moraine between this point and Kiel reached limestone at 30 to 90 feet.

An esker which extends southeastward for 3½ miles from sec. 35, T. 18 N., R. 20 E. (Charlestown Township), through the northeast part of New Holstein Township, to the moraine 2 miles north of Kiel marks a line of glacial drainage whose direction of flow was the reverse of Pine Creek, the present stream. The esker is a small ridge of coarse gravel 5 to 20 feet high, continuous except at three places. It is best developed near where it crosses the road at the north line of New Holstein Township just west of Pine Creek. The gravels exposed in this road cut are poorly assorted, including stones a foot long, and are not well bedded.

Half a mile northwest of the station at Kiel the railway crosses the terminal moraine. It is here a low ridge about half a mile in width with surface marked by sags and swells. From the railway this moraine extends about 18 miles in a nearly direct line to the Niagara escarpment near Peebles station in T. 16 N., R. 18 E. (Taycheedah Township). Through much of this distance it is a well-defined ridge with its surface pitted with sags. One to two miles northeast of St. Anna the morainal deposits overlie and almost obliterate a drumlin topography. Where crossed by the road a mile west of St. Anna the ridge is about 80 rods wide and 80 feet high. Because of their strong development in this vicinity the deposits may be designated the St. Anna moraine.

In northern Marshfield Township (T. 16 N., R. 19 E.) the deposits spread out as a pitted tract 1½ miles wide without definite ridge form. From the south side of this belt a flat outwash gravel terrace of nearly 4 square miles spreads out to the big tamarack swamp between Calvary and St. Cloud. Wolf Lake occupies a large ice-block depression in the gravels.

From a point 2 miles north of Calvary southwestward for about 5 miles the morainal deposits consist of poorly defined patches of gravels, marked by slight sags and swells scattered amongst the drumlins and in a few places partly covering them.

Three miles northeast of Peebles the morainal belt becomes more definite and its trend changes to somewhat west of south, so that the deposits lie on the margin of the upland just east of the crest of the Niagara escarpment. Farther south, in the northwestern part of Empire Township, the deposits drop down over the edge of the escarpment and thence southward to Lake de Neveu lie banked against the face of the bluff, showing that the ice was confined to the valley.

Rienzi Cemetery, 3 miles east of Fond du Lac, in the NE. ¼ sec. 19, T. 15 N., R. 18 E. (Empire Township), is situated on this moraine. In the upper (eastern) part of the cemetery the ledge of limestone begins to emerge above the moraine. Not more than 30 rods west of the ledge the cemetery well is said by J. E. McCormick, who lives near the foot of the slope, to have penetrated the following:

Log of well at Rienzi Cemetery, sec. 19, Empire Township.

	Feet.
Glacial till, whitish and bluish clay	150
"Cincinnati" shale	150
Galena dolomite and Trenton limestone	200
	500

Morainal gravels are exposed along the slope between St. Agnes's Convent and the flour mill, and again above the ledge east of Lake de Neveu. H. G. Hass's gravel pit exposed the following section:

Morainal drift, H. G. Hass's gravel pit, SE. ¼ sec. 30, Empire Township.

	Feet.
Buff, semistratified till	3 to 4
Fine and coarse, poorly stratified gravel	6 to 7
Beautifully stratified and cross-bedded fine gravel and sand; beds dip south	9

The basin of Lake de Neveu is a depression left by the melting of a great ice block which was buried in morainal drift at the stage under discussion. The position of the ice front in southern Fond du Lac Township and northern Byron Township is not indicated by morainal deposits. It was probably confined to the valley below the escarpment.

That a short stand of the ice front followed a slight recession from the St. Anna moraine is shown by a branch that diverges a mile northwest of Kiel and that may be traced 4 or 5 miles nearly due west. This branch is very small, rarely more than a rod or so wide and 5 to 10 feet high, yet it is distinctly traceable across hills and valleys, showing the position held by the ice front. About 3 miles southwest of New Holstein it curves southward 120 rods as the result of a slight lobation of the ice due to a small valley. West of this it may be traced diagonally up the steep slope of a drumlin to a height of 100 feet or more above the stream and thence westward for 1½ miles across other drumlins. Scarcely a trace of this branch is seen beyond the west line of New Holstein, unless some of the small morainal patches east of Johnsburgh and Malone are such.

No distinctive deposits belonging to the St. Anna moraine have been noted westward through northern Byron Township or southern Fond du Lac Township. It is probable that the ice front was bordered by ponded waters across this tract and that the deposits are represented by lake silts beneath the flat plain rather than by a marginal moraine. These waters escaped southwestward by cutting through the gravel terrace at the head of Horicon Marsh.

From east of the village of Sevenmile Creek, however, a fairly well defined moraine extends northward to Eldorado and thence through northeastern Rosendale Township (T. 16 N.,

R. 15 E.) into Utica Township, Winnebago County, where it swings northwestward, crossing the Chicago, Milwaukee & St. Paul Railway near Elo; then, turning westward for 3 miles, it curves to the north between the big marsh and Rush Lake, showing the position of an ice lobe which lay in the depression formed by the big preglacial valley. Wells, some of which do not penetrate the full thickness of the deposits, show 60 to 90 feet of drift in this part of the moraine. This moraine shuts in the basin of Rush Lake on the northeast.[1] Farther northward, in the vicinity of Waukau, the moraine disappears, evidently having been overridden by the ice depositing the red till moraine. When the ice stood at the St. Anna moraine the waters ponded in Rosendale, Lamartine, and Oakfield townships must have escaped southward to Horicon Marsh and Rock River, those in Rush Lake basin must have discharged southwestward, and those in the Fox River basin must have continued to discharge at Portage.

Where best developed this moraine is a well-defined knolled and pitted ridge not over half a mile in width. Two miles north of Eldorado a moraine-like ridge branches from this belt and extends northeastward to the middle of the west line of sec. 3, T. 16 N., R. 16 E. (Eldorado Township), where it terminates in an abrupt group of kames, about which, on the east and north, curves the outer marginal slope of the red till moraine. As no red material is intermingled with the unassorted mass of subangular stones and clay exposed in a 20-foot excavation it is clear that the kames belong to an earlier deposit and just escaped being overridden when the glacier readvanced and deposited the red till.

LITHOLOGIC COMPOSITION OF RECESSIONAL MORAINES AND ESKERS.

Estimates were made of the composition of the drift of the recessional moraines, based on the examination of nearly 3,000 pebbles at 23 different places, mostly in the eastern part of the moraines and in some associated kame tracts. Of the pebbles examined, about 9 per cent were of rocks foreign to the area, most of them crystalline rocks from Canada. At some of the exposures, particularly west of the Niagara escarpment, from 95 to 99 per cent of the pebbles were from the local limestones. Comparison shows the percentage of foreign material to be a little lower than in the Lake Border moraines of the Lake Michigan Glacier, where 11.19 per cent of the pebbles were foreign. Intermediate between the two is the drift of the Kettle interlobate moraine, where the foreign constituent was 10.38 per cent. Four estimates of pebbles in eskers associated with these moraines showed an average of only 7 per cent foreign material. At one section of the esker, in western Rosendale Township (see p. 299), 97 per cent of the pebbles were from the local limestone. This certainly looks like drift from the base or lower part of the glacier.

One of the Wisconsin drift diamonds, a 21¼-carat stone, is reported to have been found in 1886 near Kohlsville (on or near the Green Lake moraine) by a farmer named Endlich. (See pp. 221, 259, 270, and 308.)

LAKE BORDER MORAINIC SYSTEM.

GENERAL FEATURES.

In his studies of the drift in Illinois Leverett[2] found a system of ridges continuing southward from the Wisconsin line into Cook County, Ill., between the Valparaiso morainic system and the lake shore. The northward continuation of this system of ridges in Wisconsin, called by Leverett the Lake Border morainic system, is shown on Plate III (in pocket). Although, in large part, these ridges are clearly marked and are distinctly separated, so as to give the peculiar north-south trend to the drainage lines, they are cut through at intervals by streams, and in some places contiguous ridges coalesce, so that there may be some difference of opinion as to their exact correlation. This is, however, of little moment so long as the distinctive features of the topography are recognized.

The topography of these drift ridges in the southern counties is marked, in general, by the gently flowing contours characteristic of drift overridden by the ice, whence they appear to be of the lodge moraine type.[3] Here and there groups of kettle holes pit the surface, and in some places considerable deposits of gravel occur. Surface bowlders are very abundant in parts of Greenfield and Franklin townships, Milwaukee County. They were formerly much more abundant on the ridge nearest the lake,

[1] See Ripon topographic map.

[2] Leverett, Frank, The Pleistocene features and deposits of the Chicago area: Chicago Acad. Sci. Bull. 2, Geol. and Nat. Hist. Survey, pp. 42-47, 1897. Also, The Illinois glacial lobe: U. S. Geol. Survey Mon. 38, pp. 380-412, 1899.

[3] Chamberlin, T. C., Proposed genetic classification of Pleistocene glacial formations: Jour. Geology, vol. 2, pp. 525-526, 1894.

but have been largely collected and used in the construction of piers, breakwaters, and other structures.

MORAINAL RIDGES.

SOUTH OF MILWAUKEE.

The most westerly of the morainic ridges is that lying just west of the continuous valley, occupied in part by Underwood Creek, in part by Root River, and in part by Des Plaines River. The crest of this ridge, which stands 220 to 360 feet above Lake Michigan, decreases in elevation from north to south; the width varies from 1 to 4 miles. On the west the slopes rise gently 20 to 60 feet above the adjacent marsh and ground-moraine tracts; on the east they drop 100 to 180 feet to the adjacent valley bottom. Through most of the distance from Menominee Falls, in northeastern Waukesha County, to Union Grove, in Racine County, the crest of this ridge forms the divide between the waters tributary to the Great Lakes and those belonging to the Mississippi system. Just east of Union Grove the divide crosses to the east side of the Des Plaines Valley. At the point of crossing the divide is scarcely perceptible, being in a nearly continuous marsh, from which the waters of Root River flow north and those of Des Plaines River flow south.

Though the surface of this west ridge is in general very gently undulating, it possesses certain slight features, such as small, irregular, sharply depressed swamp and marsh areas, groups of kettle holes, tracts marked by sags and swells, and abundant foreign bowlders, all of which are characteristic of terminal moraines. Gravel deposits, though frequently met in drilling wells in this belt, are not plentiful upon the surface.

The known thicknesses of the drift in this belt range from a few feet, where the rock elevation at the Trimbone quarry, in the town of Greenfield, Milwaukee County, is crossed, to 225 feet, in the northwestern part of Raymond Township, Racine County. In general, the thickness of the drift is greater south of the town of Franklin than north of it. A part of this drift was probably deposited during the earlier ice advances, but no definite horizon separates the earlier from the later drift.

The great bulk of the material composing this ridge, as also the ridges to the east, is moderately stony, calcareous, bluish till, whose upper part is generally oxidized to light buff. Over this there is a goodly coating of humus. At a few places in the southwestern part of Milwaukee County the subsoil is brownish in color and putty-like in consistency; at some places it is pinkish and at others is slightly purplish. At many exposures the till is very stony but in general is notably less so than the drift of the areas to the west. In places the clay is nearly stoneless near the surface, but becomes increasingly so downward in the exposed sections. The rock fragments are generally small and well glaciated, bowlders a foot or more in diameter not being plentiful. Most of the wells penetrate more or less sand and gravel; many, however, find only a few feet of such material and some find none at all. Herman Blink's flowing well, about 4 miles southeast of the village of St. Martin, penetrated nearly stoneless blue clay to a depth of 200 feet. Some other wells pass through 150 to 200 feet of clay before finding much sand or gravel. In a well on the ridge about a mile southeast of Bristol, below 40 feet of clay, loose fine sand was struck which continued, with streaks of clay, to a depth of 240 feet, where the well was abandoned.

East of the Des Plaines-Root Valley is a broad middle belt, with a topography like that of the west ridge. In southern Milwaukee County this is marked by two more or less distinct crests. In Racine and Kenosha counties there are two distinct ridges, the west one of which has two crests. In the towns of Pleasant Prairie and Bristol, in southeastern Kenosha County, this middle belt is crowded out by the convergence of the ridges on either side.

Like that of the west ridge just described, the surface of this middle belt is in general very gently undulating, though the west crest is marked by a mild morainal topography in Greenfield and Raymond townships (Tps. 6 and 4 N., R. 21 E.) and the southwestern part of Caledonia Township (T. 4 N., R. 22 E.).

So far as known the drift in this belt ranges from 30 to 300 feet in thickness, the greater thicknesses being in the southern part of Milwaukee County. The composition of the drift in general is about the same as that on the west ridge. At numerous places on the west crest and quite generally on the east crest, in that part of Milwaukee County within this district, a reddish clay subsoil occurs. Where exposed at the surface the reddish color has been more or less washed out of the surficial part, giving to the soil a grayish cast. Thicknesses of this reddish clay varying from a few inches to 17 feet have been found.

The most strongly marked of the morainal ridges from Milwaukee southward is that nearest the lake shore. This ridge ranges in width from 1 to 4 miles, and its crest is 120 to 140 feet above the lake. It is thus 50 to 60 feet lower than the higher crest of the middle belt and about 120 feet lower than that of the west ridge. It is bordered on the west by a broad valley, from whose bottom the slope rises 40 to 60 feet. Where this valley is occupied by Root and Pike rivers the relief has been somewhat increased by postglacial erosion. In general the east slope is longer and less abrupt than that on the west slope, but for 10 miles in southern Milwaukee County and Northern Racine County most of the east slope has been cut away by the encroachment of the lake. The bluff thus formed rises 100 to 160 feet above the water's edge.

Like the other ridges, the surface of this east ridge is marked by very gentle undulations. Southeastward from the vicinity of Wauwatosa to the lake shore near Cudahy, there is a nearly continuous deposit of gravels, marked by knolls and kettle holes. South of Kinnikinnic River this gravel belt lies just northeast of the main ridge with, in places, a distinct valley between. A similar belt of gravels borders the valley of Oak Creek for a mile above its mouth. So far as can be learned from wells there is less of sand and gravel in this ridge than there is in the vicinity of Milwaukee and Wauwatosa. As in the other ridges so here also, at many places in Milwaukee County, the upper part of the drift below a few inches of soil is reddish to reddish brown in color. This usually grades downward into bluish till in a few feet; but some wells have been reported as penetrating 15 to 18 feet of this reddish clay before reaching the blue clay. In general, however, the upper 5 to 15 feet of the till is oxidized to a light-buff color which gradually becomes bluish below. In places the soil is a loose sandy loam; elsewhere it is more of a loamy clay. In parts of Racine and Kenosha counties the crest of the ridge is a grayish clay, becoming bluish below.

The 10-mile section afforded by the lake bluff in southern Milwaukee County and northern Racine County exposes 60 to 160 feet of drift. It is probable that a considerable part of the drift here exposed was deposited not during the final melting of the ice but during the glacial advance; but the deposits of the advance and retreat can not be readily distinguished in the exposure. It is also possible that some of the exceedingly hard, brown and reddish-brown clay in the lower part of the bluff section was the deposit of an earlier advance of the ice and was overridden during the later advance.

From Bay View southward to the intersection of the east ridge, about a mile northeast of Cudahy, lacustrine deposits are exposed in the bluff. More or less stony till occupies the lower part of this section and rises as the moraine is approached, until at the point where the moraine is cut the full section is of buff and blue stony till. This unstratified material continues southward about one-half mile. South of this to the mouth of Oak Creek, a distance of 3½ miles, the bluff is very largely composed of stratified beds of sand, gravel, and clay. South of Oak Creek the bluff is mostly of clay, buff above and bluish below, beneath which lies the dense brownish deposit thought to be of earlier age. The clay generally contains little stone. At the point where Root River swings eastward to cut through this ridge an excavation exposed about 15 feet of beautifully interlaminated sand and clay overlying coarse gravel. About a mile east in the same valley a similar series of finely interlaminated clay, sand, and gravel is underlain by dense bluish stony till and is overlain by blue till, which grades upward into buff till and buff sandy clay. Both stratified sections indicate lacustrine conditions; the latter shows the occurrences of such conditions between two deposits of till. The observed thicknesses of drift in this east ridge range from 25 feet to more than 200 feet.

WAUKESHA, MILWAUKEE, WASHINGTON, AND OZAUKEE COUNTIES.

In Waukesha and Milwaukee counties and in the towns of Germantown and Mequon, Ozaukee County, the system consists of three ridges 1 to 3 miles in width. The slopes are gentle and the reliefs on the east are usually about 100 to 150 feet, though in places less or greater. The reliefs of the several ridges on the west are commonly not much more than half as great as those on the east, as the ridge crests lower successively to the east. The general elevation of the west crest is 880 to 940 feet above the sea, that of the middle ridge 800 to 860 feet, and that of the east ridge 780 to 800 feet. These ridges are the main features of the topography. Farther north, through Germantown, Mequon, Jackson, and Cedarburg townships (Tps. 9 and 10 N., Rs. 20 and 21 E.), the ridges split up into four or five moraines of much less bulk, in places but 40 to 80 rods in width, which overlie the ground-moraine topography without greatly obscuring it. In this part the moraines are more largely characterized by sags and swells, knolls, and sharper kettle holes than farther south.

Numerous well records show an alternation of considerable thicknesses of till and of sand and gravel, evidently the results of deposition associated with oscillations of the ice front of greater or less extent. Others, however, show only till throughout thicknesses of 100 to 200 feet.

In the southeastern part of Trenton Township (T. 11 N., R. 20 E.) the west ridge of this system merges with a broad belt of terminal-moraine deposits which extends directly westward into the town of West Bend and thence northward through the towns of Barton and Kewaskum. A very slight morainal belt, apparently a branch of the broad westward-trending moraine, extends southwestwardly from southeastern Trenton Township to and beyond the vicinity of Mayfield, and coalesces with the first recessional moraine which borders the interlobate moraine on the east. In Trenton, West Bend, Barton, and Kewaskum townships the moraine ranges in width from 1½ to 4 miles or more. Its topography is characterized in parts by strongly marked knobs and kettles and serpentine kames, with numerous irregular depressed areas inclosing tamarack swamps. Reliefs of 60 to 100 feet occur among the surface irregularities. In some places gentle sags and swells occur, or simple undulations of the ground-moraine type. Generally speaking, the terminal-morainic character of the belt is clearly marked.

Most excavations in the moraine expose sand and coarse gravel. In contrast with the other moraines of the area, where the assorted deposits are usually covered by more or less clay or till, loose sand and gravel lie at the surface throughout a large part of this moraine, especially in the towns of West Bend and Trenton townships.

For about 3 miles in Trenton Township a gently sloping plain, perhaps an outwash terrace, declines southeastward from the south margin of the moraine, which is quite distinctly marked. A similar gentle slope borders a part of the south front of the slight morainic belt running through Mayfield. The relations of these moraines and bordering terrace-like slopes lead to the conclusion that while the ice front continued at the west ridge in Waukesha County a notable reentrant angle was developed in the glacial margin in southern Washington County, freeing the town of Richfield and a large part of the towns of Polk, Jackson, and Germantown (Tps. 8 and 9 N., Rs. 19 and 20 E.) of ice and leaving a lobe on the north extending westward nearly to the interlobate moraine in the towns of Farmington, Trenton, West Bend, Barton, and Kewaskum (Tps. 12 and 13 N., Rs. 19 and 20 E.).

For convenience of reference this lobe may be designated the West Bend lobe.

SHEBOYGAN COUNTY.

From West Bend northward the morainal deposits of this stage merge with the interlobate moraine previously deposited. When the head of the interlobate valley was near Dundee, a stream flowing southeastward in an ice channel or in a tunnel beneath the ice entered the valley about a mile east of Dundee. The gravels assorted by this stream now compose the esker extending southwestward from about 1¼ miles north of Parnell. The melting of the ice walls of the channel left the coarser gravels in the form of a sharp narrow ridge, from 5 to 35 feet high, which may be traced for nearly 4 miles in a sinuous course through the surrounding tamarack swamps and morainal deposits. This esker may be seen in its finest development near the fork of the road 1½ miles west of Parnell, sec. 20, T. 14 N., R. 20 E. (Mitchell Township).

It is probable that the head of the interlobate valley at this stage was gradually extended northeastward into the town of Greenbush. The widening of this interlobate space carried back the front of the Lake Michigan Glacier to a position just east of the line of this esker and caused the deposition of a well-marked terminal moraine extending northeastward through the town of Mitchell. The southeast front of the moraine is well defined where it rises abruptly from the margin of the plain or terrace on which Parnell now stands. West of this flat terrace through the terminal moraine the topography is strikingly different, the moraine being largely wooded and the surface exceedingly irregular, owing to the close succession of kettle holes and of knobs and winding ridges of gravel. Kame and kettle topography of the finest type occurs a mile north of Parnell.

In northern Mitchell Township and southeastern Greenbush Township the moraine becomes very bulky, and the higher parts reach an elevation 1,250 feet or so above the sea. None of the wells in this higher part of the moraine reached the rock, though several were reported to range in depth from 120 to 240 feet. Only a part of this mass of drift was deposited at this particular stage. The Green Bay ice front stood at the Green Lake moraine, and the interlobate angle was extended northward to about 2 miles south of Greenbush. Waters from this angle, principally from the Lake Michigan side, developed the pitted terrace between the two belts of morainal topography in southern Greenbush Township and escaped southward along the valley between the Green Lake and interlobate moraines. (See p. 294.)

At the next stage, while the Green Bay Glacier stood at the Waupun moraine and the Lake Michigan Glacier farther south was forming one of the intermediate moraines of the Lake Border system, the front of the West Bend lobe stood at a morainal belt which may be traced northwestward from Newburg in Trenton Township, through Farmingtown Township, and thence northward along the east side of the interlobate tract.

In the area between this moraine northwest of Newburg and the outer moraine of the West Bend lobe, an extensive deposit of stratified sand and gravel with some clay is marked in part by gentle undulations and in part by low broad-topped elevations with abrupt marginal slopes. A broad flat borders the river and large swamp areas occur. Exposures near the railway track south of Wallace Lake and at the pit of the Pick Brick Co. one-fourth mile farther southwest give 20 to 35 foot sections of the deposits. The lower part of the exposed material is fine, laminated, calcareous, reddish clay, with some interlaminated sand. Small clay concretions also occur. Overlying this clay is clean fine sand, stratified and cross-bedded, but containing little or no gravel. The sand is calcareous, being composed in part of small crystals of dolomite, so that calcareous efflorescence forms on the face of the bank. At the brick factory 2 to 3 feet of fine gravel occurs at the top of the exposure. Throughout the tract the soil is loose sand with a small amount of fine gravel. In most cases the bedding dips westward or southwestward.

The deposit is evidently one formed in waters ponded between the retreating front of the West Bend lobe and the outer moraine. Deposition probably took place very close to the ice front, so that there was not everywhere complete assortment of the material. There was, however, much more assortment and stratification than in ordinary ground and terminal moraine deposits. The glaciolacustrine deposits merge with those of the terminal moraine, so that no sharp line can be drawn between them. Much of the sand and gravel south and west of Milwaukee River is glaciolacustrine rather than morainal, as depicted on the map. In the western and southern parts of the basin the deposits rise to about 960 to 970 feet above sea level, corresponding in elevation with the lowest part of the morainal crest in sec. 36, T. 11 N., R. 19 E. (West Bend Township), where a spillway may have been located. An abrupt east margin extending southward from the vicinity of Wallace Lake may mark the position of the ice margin at the highest stage of the lake.

In Scott Township, Sheboygan County, the village of Beechwood stands on a slightly pitted gravel terrace which extends northward and is nearly continuous with a similar but more extensive terrace on which stands the village of Parnell. On the west these terraces are bordered by the terminal moraine previously described. On the east abrupt, knolled and pitted, ice-contact slopes mark the position of the ice front when the terraces were formed by the deposition of gravels washed out by the glacial drainage. The slight southwestward slope of the terraces indicates the direction of flow of the waters which escaped through the moraine to the valley south of the village of Jersey. About 3 miles northeast of Parnell, in the SE. $\frac{1}{4}$ sec. 2, Mitchell Township, the terrace ends and the ice-contact slope merges with the great moraine. Thence northward to Glenbeulah, where the ice fronts converged, the glacier contributed to this moraine.

Wells 150 to 180 feet in depth on these terraces do not reach bedrock. The well of C. W. Humphreys, about a mile northeast of Parnell, in gravels that lap around the slopes of a previously deposited till hill, penetrated 17 feet of gravel over 163 feet of hardpan or till. Another well, a mile farther northeast, on the broken margin of the terrace, penetrated 15 feet of clay and 105 feet of successive beds of gravel and hardpan. Probably only the clay and the upper gravel bed were deposited at this stage.

A slight recession of the front of the West Bend lobe led to the formation of the morainal deposits that extend westward from the vicinity of Waubakee south of Kohler to Fillmore and thence northwestward past Boltonville, and of the gravel terraces 2 to 3 miles southeast of Beechwood. The opening of new outlets for the water led to the formation of a second and lower terrace bordering the Parnell terrace on the east and best developed 1½ to 3 miles northeast of Parnell. Remnants of this terrace east and southeast of the village border the valley of Stanley Creek, which was further deepened by the subsequent erosion. A short distance south of Kohler the morainal deposits surround a finely formed drumlin.

A further slight recession of the two ice fronts led to the formation of the Rush Lake moraine and to the completion of the great morainal ridge extending north to Glenbeulah. The east front of this moraine rises about 200 feet from the bottom of the valley on the east to an irregular, terrace-like shelf seen in places along the town-line road. Southward the slope swings westward through the extreme northwest corner of Lyndon Township (T. 14 N., R. 21 E.) into the northeast part of Mitchell Township. Here the shoulder becomes a definite terrace, the third and lowest of a set of which the Parnell terrace was the first and highest. This third terrace leads southward directly into the head of the Stanley Creek valley and there can be no doubt that the outflow of glacial waters formed the terrace and the deep sinuous flat-bottomed valley part by deposition and part by the erosion of earlier deposits.

With the terrace and valley are probably to be correlated the morainal and terrace deposits near Cascade in the southwestern part of Lyndon Township. For 6 miles southward only very slight traces of morainal deposits were found. One mile west of the village of Silver Creek, in sec. 31, T. 13 N., R. 21 E. (Sherman Township), a sharp morainal ridge occurs; and between this place and Waubakee a line of deposits probably marks the complete disappearance of the West Bend lobe. Three to four miles north of Waubakee the morainal deposits partly bury and surround drumlins which were formed previously. Two small eskers in secs. 4, 5, 8, and 6, T. 12 N., R. 21 E. (Fredonia Township), about a mile each in length, mark the positions of subglacial streams. One of these terminates in a delta or terrace well up on the slope of a hill, as though the stream had discharged into a bordering lake at this level.

About the time the Green Bay Glacier was forming the St. Anna moraine the Lake Michigan Glacier was probably depositing the east ridge of the Lake Border morainic system in Kenosha, Racine, Milwaukee, and Ozaukee counties. What is regarded as the continuation of this east ridge may be traced in a direction somewhat east of north from near Waubakee and Fredonia to a point 3 miles northeast of Random Lake, where it is overlapped and buried by the red till.

Between Waubakee and Random Lake, in an extensive pitted gravel terrace formed by outwash from the ice front, Spring and Random lakes occupy depressions left by the melting of buried ice blocks. From the vicinity of Random Lake northward for 10 miles no trace of the moraine is seen west of the red-till area, unless a part of the big ridge, which rises 225 feet just west of Hingham, is such. Red till is exposed on the east slope of this hill nearly to the top, but not in excavations in the upper west slope. West and northwest of the vicinity of Waldo is an elevated tract of several square miles in which wells 140 to 220 feet deep do not reach bedrock, but the configuration of its surface is that of a gently rolling ground moraine rather than a terminal moraine. From the valley of Union River to a point a mile northwest of Plymouth is a similar elevated tract, narrowing at the north to a ridge 200 feet in height. The surficial configuration of this ridge and the gravels and bowldery drift exposed in cuts indicate that it was completed, at least, by marginal morainal deposition.

MANITOWOC COUNTY.

From the bend in Mullet River, north of Plymouth, northward for about 2 miles on the east side of the stream, there is some question as to how much of drift of the ridges is morainal. Near the north line of the township (T. 15 N., R. 21 E.), however, and thence northward through Rhine Township, southeastern Schleswig, and the western parts of Meeme and Liberty townships, Manitowoc County, morainal topography is well developed.

The village of Elkhart Lake stands on a plain or terrace in the midst of the moraines. The general flatness of the surface is well marked, especially near the village, but in places the gravels are so pitted with ice-block depressions that the terrace aspect almost disappears, and, in fact, it does disappear at the east and the west by gradation into kame and kettle topography. Remnants of a terrace occur on the east side of the valley 2 to 3 miles south of Elkhart and also on the south side of the river a mile east of Glenbeulah. Between 1½ and 3 miles northwest of Plymouth two terraces and a remnant of an intermediate one occur west of the river. The highest of these terraces, which leads southward into the head of the valley 2 miles west of Plymouth, is probably to be correlated with those farther north. These terraces were formed by the deposition of gravels washed from the glacial front. The abundance of depressions with which they are now pitted indicates that a great deal of ice was buried in the drift, and that before these masses melted or the streams had cut into the gravels the terraces were more continuous.

If, as seems probable, the Green Bay Glacier had by this time melted back from the moraine near Glenbeulah and Elkhart Lake an extensive body of water must have been ponded between this moraine and the ice front on the west. Part of the water flowing from the Lake Michigan Glacier and depositing these terrace gravels may have drained into this temporary glacial lake. The water forming the south terrace escaped southward through the valley between the big morainal ridges west of Plymouth.

The area to the east now traversed by Sheboygan and Mullet rivers was still buried beneath the ice, and the Onion River valley was not yet opened as far south as Waldo, so the glacial waters were forced to cut through the drift ridge in the E. ½ sec. 7, T. 15 N., R. 21 E. (Lyndon Township), 2 to 3 miles above Cascade. South of this they entered the valley of the north branch of Milwaukee River. The outlet cut by this glacial drainage in the E. ½ sec. 7, which is not now traversed by any stream, is interesting as an example of a channel eroded under the special conditions which controlled the glacial drainage. A similar channel one-half mile west of Cascade was possibly formed at about the same time. The Milwaukee River valley was not yet open below Waubakee, so that the waters escaped across the moraines to the southward.

In adjacent parts of Liberty, Meeme, and Schleswig townships, Manitowoc County, 1½ to 3 miles south of St. Nazian, a gently west-sloping tract pitted like a gravel terrace is bordered on the south by a short abrupt slope like an ice-contact margin and on the east and north by morainal topography. The relations indicate that this terrace was formed from gravels washed from the front of the Lake Michigan Glacier.

The position of the interlobate angle to which the fronts of the two glaciers converged while these various deposits were being formed is not known. The glacier later readvanced over the angle and transversely over the deposits, burying them beneath the red till, whose border lies about 2 miles north of the north boundary of the area under discussion. Hence the relations of the moraines of the two glaciers can not now be determined.

LATER MORAINAL DEPOSITS.

South of the intersection of the moraine by the lake bluff northeast of Cudahy no further morainal deposits are found, owing to the encroachments of the lake, but north of this point the ridges shift westward and later deposits remain. West of Milwaukee River traces of a later moraine are seen in two ridges, one of which extends about 2½ miles north-northwest from Reservoir Park, through the thirteenth and twenty-first wards, and the other 2½ miles slightly east of north from a point 1¾ miles north of the railway junction at North Milwaukee. The latter ridge carries upon its surface abundant crystalline bowlders, some of which are large. One mile west of this ridge is another elevated tract. Some slight morainic features occur also in the vicinity of South Park, in the seventeenth ward.

Farther north the later morainal deposits were modified by lake action or were overridden and mantled with red clay at a readvance of the glacier.

LITHOLOGIC COMPOSITION OF THE LAKE BORDER MORAINES.

In order to determine the constituents of the drift of the Lake Border moraines 8,000 to 9,000 pebbles, taken from 52 different places along the moraines, were examined. Of these 11.19 per cent were of rock foreign to the part of Wisconsin east of the Kettle interlobate moraine, 10.30 per cent being of crystalline rocks from Canada, and 0.89 per cent of sandstones and quartzites from the Lake Superior region. Most of the remaining 88.81 per cent were limestone pebbles, principally from the Niagara dolomite, with small contributions from the Waubakee and Milwaukee formations.

Near Milwaukee River, about 3 miles north of Saukville, Ozaukee County, a fifth diamond was found in the Wisconsin drift in 1896 by a farmer named Conrad Schaefer. This and the other diamonds (see pp. 221, 259, 270, and 301) are of interest principally in showing that somewhere to the north in the region of Hudson Bay there is diamond-bearing rock.

KETTLE INTERLOBATE MORAINE.

In southern Kewaskum Township two bulky morainal ridges and one smaller intermediate ridge extend southward. The west ridge is half a mile to a mile in width and 200 feet in height. It appears to belong with the Green Lake moraine and to be continued by the belt extending northward from the vicinity of Kewaskum. The intermediate ridge, though bulky west of Barton, dwindles northward, and is cut through by the river 2 miles below Kewaskum near the point where it merged with the bulky east ridge. The east ridge appears to represent the Kettle interlobate moraine from Barton northward. Through eastern Kewaskum Township and to a point a mile northeast of Elbesville the moraine is a massive wooded ridge, much broken by kames and kettle holes, whose west slope drops abruptly 100 to 150 feet to the valley now drained by the east branch of Milwaukee River. This is one of the finest examples of terminal-moraine topography in the United States. The west front is much pitted and is probably an ice-contact slope against which the front of the Green Bay Glacier pressed. Near West Bend and again south of St. Michaels this moraine is joined by recessional moraines of the Lake Michigan Glacier; farther northward the ice on the east probably continued to add to the interlobate deposit, while the Green Bay front stood at the moraine on the west side of the valley from Kewaskum to Dundee.

The combined morainal deposits spread over a tract nearly 3 miles wide between Elbesville, Jersey, and Beechwood. The relief here is less, and the moraine is interspersed with tamarack swamps and small lakes. Near Jersey the west front becomes abrupt again and 150 to 160 feet in height. Northeast of the village the top of the moraine is flat and terrace-like. Near Dundee the later deposits of the Lake Michigan Glacier swing more to the east and become more distinct from the interlobate moraine, being separated therefrom by the large tamarack swamp in the town of Mitchell (T. 14 N., R. 20 E.). East of Dundee and Long Lake the interlobate moraine changes in character; throughout an area of 5 or 6 square miles it becomes, instead of the massive morainal ridge it formed farther south, a gently rolling plain resembling ground moraine, above which rise numerous great detached kames with very abrupt slopes that rise 60 to 150 or more feet to small conical crests.

This topography was probably near the head of the interlobate valley when the two glacial fronts occupied the Green Lake moraine, the west ridge of the Lake Border moraines, and the moraines on either side of this valley, the great kames being due to accumulations of gravel washed into crevasses or moulins by streams flowing in ice channels through the trough between the frontal slopes of the coalesced glaciers. The course of one of these streams from the Lake Michigan Glacier is marked by an esker which extends southwestward from 1¼ miles nearly north of Parnell to 1 mile east of Dundee; a similar stream from the Green Bay Glacier followed the line of the esker southeastward from Mitchell post office; and a third formed the esker which traverses the dry bed of Bear Lake in the southwestern part of Greenbush Township (T. 15 N., R. 20 E.).

Continued melting extended the interlobate valley northeastward to a point about 2 miles south of the village of Greenbush; and in this angle, between the great moraines which were built up at the glacial fronts on either side, were formed the upper pitted gravel terraces.

From the relations of the deposits it thus appears that the strictly interlobate part of the great system of moraines between Dundee and Schleisingerville must have been formed while the ice fronts occupied the diverging Valparaiso and Green Lake moraines and were closely opposed north of the vicinity of Schleisingerville.

While the ice fronts occupied the Green Lake and Lake Border moraines and their northward continuations, no strictly interlobate deposition took place south of Dundee, the ice fronts being separated by an open valley. The deposition in the angle northeast of Dundee was not sufficient to build up a typical interlobate moraine as the head of the valley between the glaciers was being extended northeastward into Greenbush Township.

Following the next interval of recession the ice fronts converged in the massive morainal wedge south of Glenbeulah. At this stage interlobate deposition extended the Kettle moraine northward past Cedar and Elkhart lakes. It is not clear from the relations that any of the morainal deposits in southeastern Schleswig and western Meeme townships should be considered interlobate. They may all have been deposited by the Lake Michigan Glacier at the next succeeding stage.

South of Glenbeulah the drift which was deposited in the interlobate angle is piled up in a massive moraine about 250 feet in height. The combined converging moraines have a width of more than 6 miles at the south line of the township. Five miles north of this line, where the river cuts through at Glenbeulah, the great ridge ends abruptly with a width of less than 1 mile. The marginal slopes form a line of steep bluffs on the east and northwest, and much of the surface is exceedingly rough, a labyrinth of ridges, knolls, and kettle holes, many of which are large and deep. Much of this tract is still wooded where the surface is too irregular for cultivation. Two wells, 1 mile and 1¼ miles south of Glenbeulah and about 100 feet above the railway, were reported to have reached bedrock at 100 feet. M. Bruegger, a well driller, informed the writer that in drilling Mr. Foss's well, 2 miles south of Glenbeulah (sec. 13, T. 15 N., R. 20 E.) he penetrated 253 feet of gravel and sand without reaching rock. Mr. Schultz's well, about 3 miles south of Glenbeulah, penetrated 275 feet of drift. Another well in the same section (sec. 24) went through 222 feet of sand and gravel beneath 4 or 5 feet of clay.

Between the villages of Glenbeulah and Elkhart Lake, the preglacial valley of Sheboygan River, 200 feet or more in depth, lies wholly buried by the drift. Laun Bros.' well at Lakeside Park, on the west side of the lake, starting about 75 feet above the water, is reported to have penetrated 240 feet of drift without reaching rock bottom. Limestone is encountered at shallow depths both north and south of Sheboygan Swamp; and only 1¾ miles northwest of Lakeside Park limestone was exposed in deepening the channel of Sheboygan River in an attempt to drain the swamp. It is thus evident that the ancient valley in which the great swamp lies was blocked by morainal deposits in the vicinity of Elkhart Lake. Knolled and pitted topography surrounds the lake basins and these are themselves but larger depressions left by the subsequent melting of great blocks of ice. The morainal deposits here are largely sand and gravel, which, in places, are heaped up in great hills.

As evidence of the thickness of the drift (some of which may not have been deposited under strictly interlobate conditions) along the main morainal belt from northern Washington County into the towns of Meeme and Liberty in southern Manitowoc County records of numerous wells may be adduced. Five wells are reported to have reached limestone at 42 to 124 feet, an average of 86 feet. Twenty-one wells penetrated 33 to 275 feet (an average of 159 feet) of drift without reaching rock. The total average thickness of drift shown by these wells is 145 feet.

The lithologic composition shown by the average of 8 estimates made by counting and sorting pebbles is as follows:

Estimate of lithologic composition of drift of the kettle moraine.

	Per cent.
Niagara dolomite	89.37
Cambrian sandstone	.79
Huronian quartzite	.19
Crystallines	9.77
Chert and quartz	.16
Doubtful	.21
	100.49

As this moraine appears to be composed principally of sand and gravel it is probable that it includes little material from the "Cincinnati" shale.

Chapter X.—RED TILL AND ASSOCIATED LACUSTRINE DEPOSITS.

STRATIFIED DRIFT BORDERING LAKE MICHIGAN.

When the Lake Michigan Glacier melted back sufficiently, waters ponded behind the Valparaiso morainic system in the south end of the Lake Michigan basin formed glacial Lake Chicago. This lake was initiated just before the deposition of the most westerly of the Lake Border moraines. With each subsequent recession of the ice front the lake was extended northward only to be contracted when the glacier again readvanced. The highest of the abandoned shore lines of this lake, the Glenwood beach, stands about 60 feet above the present lake level, or 635 to 640 feet above the sea. Very little of eastern Wisconsin lies below this elevation, so that it was not until after the completion of the Lake Border moraines that the waters of Lake Chicago extended to Wisconsin and formed beach deposits which are still preserved and can be identified as such. In eastern Racine and Kenosha counties the Glenwood beach and off-shore deposits are well developed. (See further, pp. 326–330.)

Through the greater part of the distance between Wind Point (north of Racine) and Milwaukee such lacustrine deposits as may have been made have been removed by subsequent wave action, which has also cut away a part of the east ridge of the Lake Border morainic system.

From the vicinity of Cudahy to a point 6 miles northeast of Port Washington the lake-bluff section exposes considerable deposits of assorted and stratified drift overlying the blue bowlder clay of the main drift sheet and, north of Milwaukee, underlying a deposit of red pebbly clay. Between the north line of Port Washington Township (T. 11 N., R. 22 E.) and the south line of Sheboygan Township (T. 15 N., R. 23 E.) ancient lake terraces formed subsequent to the deposition of the red pebbly clay are preserved (fig. 18, *B*) and the bluff section is overgrown with vegetation and obscured. Through most of the distance between the south line of Sheboygan Township and Manitowoc the lower terraces have been destroyed and the stratified deposits are again exposed below the thin bed of red pebbly clay which here underlies the highest lake terrace (fig. 18, *A*). In this part of the bluff, however, the stratified beds overlie dense reddish to brownish glacial till and contorted clay. This latter till is thought by the writer (see p. 166) to belong to the same drift sheet as similar dense till that is exposed at the base of the bluff near Milwaukee below the blue Wisconsin till and that is referred to the Illinoian stage of glaciation. In Sheboygan and Manitowoc counties blue Wisconsin till was observed in the lake-bluff section at only one point—in the NE. ¼ sec. 34, T. 16 N., R. 23 E. (Mosel Township). Elsewhere along the line of the bluff section it appears to have been removed by subsequent lake, stream, and glacial action, if ever deposited. The stratified drift overlying the Illinoian (?) drift, however, is regarded as belonging to the same deposit as that intercalated between the blue and red pebbly clays of Ozaukee and Milwaukee counties. The relations of these deposits, as interpreted by the writer, are shown in figure 18.

This interpretation is somewhat different from Chamberlin's.[1] He regarded the dense red clay exposed at the base of the bluff between Sheboygan and Manitowoc as the equivalent of the red clay at the top of the bluff in Ozaukee and Milwaukee counties. Thus, he regarded the stratified beds overlying the basal red clay in Sheboygan and Manitowoc counties as later than the stratified beds below the red clay in the bluff section farther south.

The present writer thinks these two red-clay deposits are probably different and that the stratified deposits (Chamberlin's "Beach formation A" and part of "Beach formation B") are one and the same. Unfortunately, the lake-bluff section in Sheboygan and Manitowoc counties is in large part obscured by sliding and by vegetation, so that the relations are not

[1] Chamberlin, T. C., Geology of Wisconsin, vol. 2, pl. 8, pp. 219–228, 1873.

everywhere clearly to be seen. Some ravines, however, afford fairly clean sections and in these places the very dense brownish till and laminated clay (Illinoian ?) are at the base. Above are the stratified sands and clays referred to the early part of the Glenwood stage. In the upper part, at many places, is a bed of red till which the writer regards as the thin edge of the red till sheet spread over the higher area to the west and as the equivalent of the red till at the top of the bluff in Ozaukee and Milwaukee counties. Overlying this in the top layers of very fine sand, buff sandy clay, and laminated red and blue clay. As traced laterally the formation may show a uniform character for some distance or may exhibit rapid changes in structure and material. At one point it may consist almost wholly of fine sands and clays and a few rods distant may change to coarse sand and cobblestone gravel. The deposits are nearly everywhere beautifully stratified, the finer material being commonly disposed in delicately wavy lines, while sags and cross-bedding mark that which is coarser.

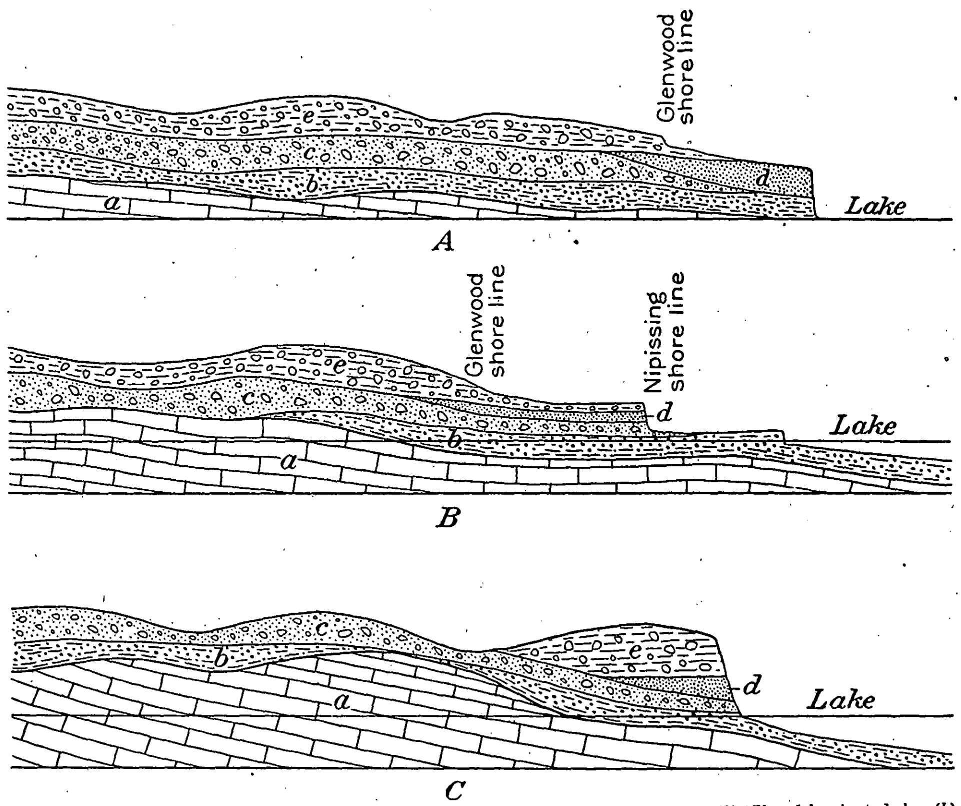


FIGURE 18.—Diagrammatic sections illustrating the relations of the bedrock (*a*), Illinoian (?) till and laminated clay (*b*), bluish-gray Wisconsin till (*c*), stratified sand, gravel, and clay of the earlier part of the Glenwood stage of glacial Lake Chicago (*d*), red Wisconsin till and laminated clay (*e*), and beach and terrace of the later part of the Glenwood stage of glacial Lake Chicago, beach and terrace of the Nipissing Great Lakes, and the present beach of Lake Michigan. Sections extend west from the lake shore: *A*, in the vicinity of Sheboygan; *B*, farther south in Sheboygan County; *C*, in the vicinity of Milwaukee.

of the bluff there is generally a thin sandy deposit.

The diagrammatic sections (see fig. 18) extending west from the lake shore show how four deposits whose stratigraphic relations are generally the same may show entirely different exposures according to the position of the section.

The assorted deposits, which range in thickness up to 30 or 40 feet, consist chiefly of sand and gravel. Interstratified with the sand are At many places the exposure of these assorted deposits is obscured by slumped overlying material; and at some places the stratified beds thin out and disappear, so that the stony red clay immediately overlies the stony bluish till; but generally the assorted drift may be traced continuously in the bluff face.

The exact conditions under which these assorted deposits were laid down are somewhat open to question. The fact that in Milwaukee and Ozaukee counties they overlie the blue till which constitutes the main drift sheet of the region indicates that the ice front had been melted back from the Lake Border moraines, when they were deposited, so that the deposition of till (*c*, fig. 18) was succeeded by aqueous deposition (*d*, fig. 18).

Extending westward 1 to 2 miles from the crest of the lake bluff in Sheboygan County a nearly flat terrace-like plain developed on the upper red pebbly clay (fig. 18, *A*) terminates at the west in a poorly developed lake shore line having an elevation above sea level of about 640 feet—the same as the Glenwood shore line farther south. There is no evidence that this ancient shore line has been elevated since its formation.

The Glenwood stage of Lake Chicago was initiated immediately on the withdrawal of the glacial front from the Valparaiso and Lake Border moraines, and during it the outlet was lowered by erosion. There is no evidence that the outlet was blocked later so as to raise the the water again to the Glenwood level, and the faint 640-foot shore line in Sheboygan County is therefore regarded as the continuation of the Glenwood beach. Further, the relations show that the assorted drift exposed in the lake bluff and the overlying red pebbly clay which underlies this beach were deposited during the Glenwood stage of the lake.

The stratified beds exposed in the bluff reach an average elevation of about 55 feet above the present beach, so that in large measure they correspond in elevation with the Glenwood stage of Lake Chicago. At numerous places, however, these deposits rise 70 to 80 feet above the present water level, which is higher than any definitely marked level of the lake about the south end of the basin, so that some special conditions must have been afforded for their deposition. These may have been furnished by the relations of the lake to the marginal drainage along an oscillating ice front. It is not necessary to suppose that the ice had entirely disappeared from the southern half of the basin so as to leave an open lake at or near whose shore the stratified beds were laid down. It is not improbable that the ice front was near by, oscillating back and forth under varying conditions of melting and advance. At times an increase of wastage may have allowed extension of the lake northward, with consequent deposition of finely interlaminated sands and silts; again, the expanding glacier may have crowded upon the land nearly as far south as Cudahy, contracting the lake to a lagoon and finally to a marginal stream. To such a stream, shifting back and forth upon the land with the oscillations of the ice front, may have been due the deposition of some of this stratified material, especially the higher level sands and gravel. Such an alternation of glacial, lacustrine, and fluvial conditions would agree very well with the variable character of the stratified beds observed.

It is indeed evident, in some places from the too great elevation, and in others from the poor assortment and lack of perfect stratification of the waterlaid drift underlying the red till, that the melting of the ice from the surface of the blue till was accompanied by the deposition of gravels with which the lake waters had little or nothing to do.

Two miles northwest of Cleveland, in Centerville Township, Manitowoc County, the abrupt side slopes of the valley of Fisher Creek expose 15 feet of coarse gravel, partly cemented to a conglomerate, beneath 10 to 15 feet of red till. This is entirely above the Glenwood level and may be a somewhat extensive deposit.

Twenty-five feet of gravel was also exposed below a thin coating of red clay in a pit opened for the electric railway half a mile south of Cedar Grove, Holland Township (T. 13 N., R. 22 E.). A well in the village is reported to have penetrated 60 feet of gravel.

A similar deposit is exposed in the lake bluff and sides of ravines cutting the lake bluff 2½ and 3 miles north of Port Washington. The section here is as follows:

Section of Lake Michigan bluff 3 miles north of Port Washington, Wis.

	Feet.
Red pebbly till	40
Coarse glacial gravels, partly cemented to conglomerate	10–15
Bluish stony till	30–35

The coarse gravels continue for nearly 2 miles in the bluff and are exposed for a mile in the sides of a ravine about 100 rods west of and nearly parallel to the shore. Farther north and south, between red and blue tills, they are replaced by sand.

Similar gravels are also exposed for more than a mile above the harbor in the sides of the branching valley at Port Washington. At the brick yards north and south of the harbor a bluff exposes fine stratified sand and clay underlying the red till, and a short distance to the west the slopes of the valley show coarse glacial gravels. In the north branch of the valley the gravels, which are partly cemented to a conglomerate, become very coarse and bowldery, like a morainal deposit. These are both overlain and underlain by bluish till, which in turn underlies the red till. These gravels are clearly glacial and were probably deposited as the ice front retreated from the east ridge of the Lake Border moraines. They may be the correlative of the morainal ridges seen in Milwaukee Township.

RED TILL AND ASSOCIATED STRATIFIED DEPOSITS.

Throughout a belt bordering Lake Michigan from Milwaukee northward a deposit of red pebbly clay, distinct in character and appearance from the bluish till of the main drift sheet, occupies an area ranging in width from barely one-eighth mile at Whitefish Bay just north of Milwaukee to 14 miles between Sheboygan and Plymouth. A similar deposit also borders Lake Winnebago and extends southward to the south line of Fond du Lac Township. (See Pl. II.)

RED TILL ALONG LAKE MICHIGAN.

CHARACTER.

Along Lake Michigan the red till, which overlies the stratified sands and gravels exposed in the lake bluff from Milwaukee northward, consists of a dense calcareous clay, varying from light terra-cotta red to brownish or purplish red, and on long exposure weathering to an ashen-drab. The color is very noticeable, giving a decidedly red tint to roads, excavations, and freshly plowed fields. In some places near the western margin of its area it becomes brownish or yellowish and is less easily distinguishable from the weathered part of the bluish till.

The bulk of the red clay is of fine grain, in some places almost putty-like. It is compact, relatively impervious, and very hard when dry, though not so hard as the typical aluminous clays. A small proportion of the grains of the various minerals are rounded, but most of them are seen under the microscope to be angular and fragmental. One ingredient is magnetite, which is the source of much of the black sand seen on the beach. This clay does not crumble loosely when it breaks down, but falls into little angular blocks one-fourth to one-half inch in diameter.

There are two more or less distinct divisions of the red clay. The lower division, which in the bluff section immediately overlies stratified sands and gravels, is usually beautifully laminated, indicating deposition in still water. At one point on the shore of Whitefish Bay the lower laminæ were observed undulating over undisturbed ripple marks at the top of the stratified sands. This laminated part usually contains no stones.

The upper division, which lies above the stratified clays exposed in the lake bluff and in slopes of tributary valleys not far from the lake shore, is unstratified and moderately stony and till-like. This red pebbly clay is the principal member of the formation throughout several hundred square miles of the deposit examined by the writer in Milwaukee, Ozaukee, Sheboygan, and Manitowoc counties. At no place other than in the lower part of the formation as exposed at or near the lake shore has any more evidence of stratification been noted than in an average section of till. The effects of weathering and vegetation might tend to obscure stratification for a few feet below the surface, but many of the exposures extend well below this zone. In places the stony material is abundant, but it is generally much less so than in the blue till exposed at the bottom of the bluff in Milwaukee and Ozaukee counties and in other parts of the area. The pebbles are usually rather small, but occasional small bowlders are seen. The stones are similar to those of the blue bowlder clay in their variety of lithologic character and angular to subangular shapes, and in showing glacial facets and striations. In other words, the red pebbly clay appears to be glacial till somewhat different in character from the bluish till previously deposited. Here and there crystalline bowlders are scattered over the surface of the red bowlder clay. At some places they are numerous, but over most of the area they are rare. North of Milwaukee County this scarcity of bowlders is in striking contrast with their abundance in the morainal belts to the west.

The combined thickness of the red pebbly clay and the laminated red clay varies considerably—in the bluff section from 1 to 80 feet. So far as has been learned from the correlation of well data the variations in general are greater than those shown in the bluff. The average thickness reported as penetrated by wells is about 34 feet.

TOPOGRAPHY.

The red till is largely disposed in a series of broad parallel ridges with gentle side slopes resembling in form and distribution the ridges of the Lake Border morainic system in Milwaukee, Waukesha, Racine, and Kenosha counties, and, like these, its topographic forms are undoubtedly due to deposition at and near the west margin of the glacier at successive stages in the final melting of the glaciers. The ridges are like till billows with the eastern slopes longer than the western, so that there is a general westerly rise of the surface. The height of the eastern slopes ranges from 40 to 140 feet; of the western from 20 to 40 feet. The crest of the most westerly ridge thus attains elevations in Sheboygan and Manitowoc counties nearly 400 feet above Lake Michigan, where in places they overlook considerable lower tracts to the west from which the red clay is absent.

This parallel ridging is particularly well developed in Milwaukee and Ozaukee counties [1] and, with the intervening sags, gives the peculiar parallel north-south trend to the drainage lines and marshes. Where erosion has deepened the troughs between the ridges the relief is of course greater. Except where so modified the troughs are of a depositional type, the sharp cutting of the streams being usually clearly in contrast with the original slopes. The shore of the lake in its present position in these counties cuts obliquely across the trend of the ridges, and the height of the bluff and the thickness of the deposit of red clay there exposed varies accordingly. This is shown very clearly where the reentrant shore of Whitefish Bay has cut nearly through the west ridge, the only one extending southward into Milwaukee County. The crest of this ridge within the Milwaukee district stands 120 to 140 feet above Lake Michigan.

Northward through Sheboygan County the east ridge continues to be well defined, as the west ridge also is in places, but the intervening belts flatten to a gently undulating plain with less definite alignment and are not shown on the map. For nearly 15 miles south of Sheboygan the east ridge is traversed by the Sauk trail road. Three miles north of Port Washington this ridge terminates at the lake shore, having been cut away by the encroachment of the lake waters. The west ridge presents at intervals well-marked characteristics of a terminal moraine, particularly 1 to 2 miles southeast of Saukville, from Fredonia northward to Hingham, 2 to 3 miles east and southeast of Rhine, and northward through Meeme and Liberty townships in southern Manitowoc County. At these places the surface of the ridge is marked by slight sags and swells with kame gravels or the ridge is particularly strongly developed. About 2 miles northeast of Random Lake the red-till moraine crosses over one of the earlier Lake Border moraines, and from this vicinity northward to Hingham the red-till moraine, or possibly the two moraines combined, form a strongly marked ridge 100 feet or more in height. (See Pl. XXXV, *A*.) In this part the margin of the red till encroaches on a drumloidal topography of the earlier advance. In Rhine and Herman townships the moraine of the red till similarly overlaps another of the Lake Border moraines; and in Meeme and Liberty townships it overlaps the Kettle interlobate moraine and is particularly strongly developed 2 miles east of St. Nazian.

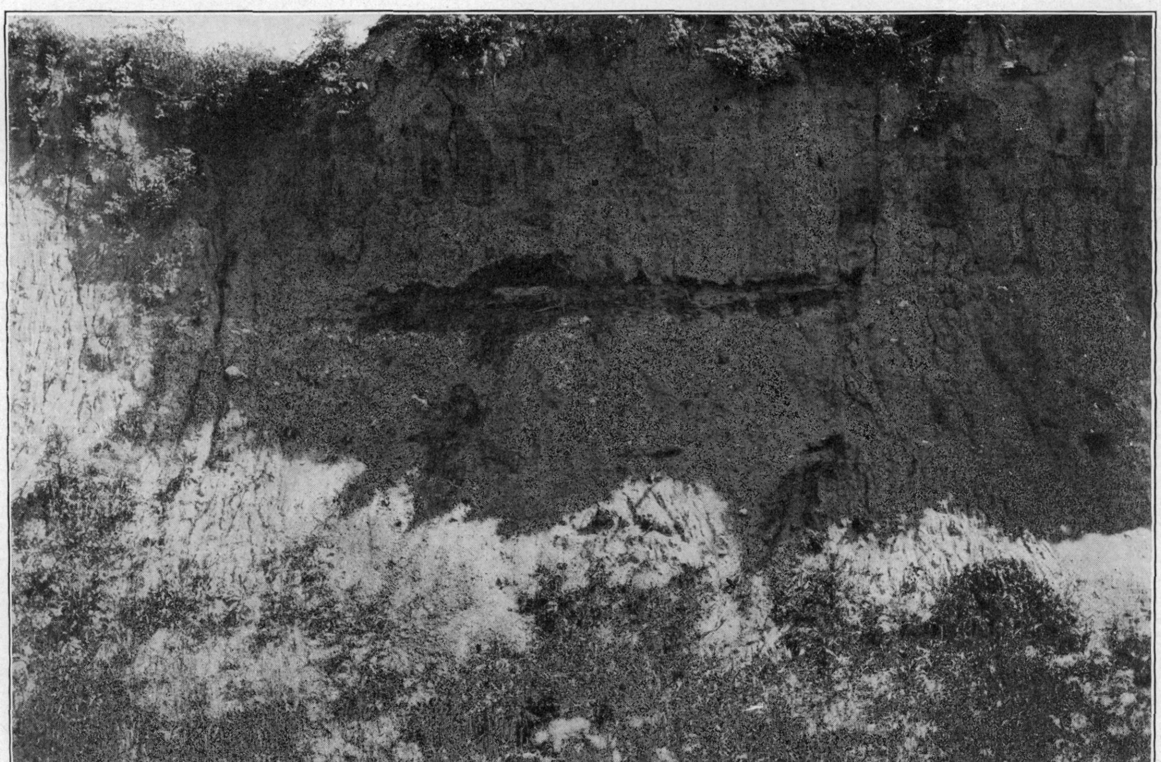
CONDITIONS OF DEPOSITION.

The conditions under which the red pebbly clay and the underlying laminated red clay were deposited seem now to be fairly well established, and the tentative hypothesis presented by the writer in the Milwaukee folio [2] may be reasserted with considerable confidence. Observation of the character and disposition of the red till throughout an area of nearly 1,000 square miles and particularly of the terminal moraine of the red till and its relations to earlier deposits has removed all doubt from the mind of the writer that the red till was the product of a distinct readvance of the Lake Michigan and Green Bay glaciers, with associated deposition in marginal lacustrine and glacio-fluvial waters.

[1] Port Washington and Milwaukee topographic maps.

[2] U. S. Geol. Survey Geol. Atlas, Milwaukee folio (No. 140), p. 6, 1906.

A. TERMINAL MORAINE OF RED GLACIAL DRIFT OVERLAPPING A LAKE BORDER MORAINE OF BLUISH-GRAY DRIFT 3 MILES NORTHEAST OF RANDOM LAKE, SHEBOYGAN COUNTY, WIS.



B. LOESS OVERLYING GLACIAL TILL OF THE WISCONSIN STAGE, CHICAGO, MILWAUKEE & ST. PAUL RAILWAY CUT 3 MILES NORTHWEST OF FALL RIVER, COLUMBIA COUNTY, WIS.

The source of the red coloring matter is not yet known. Under the microscope the color is seen to be due to a delicate coating of iron oxide on the grains of the various minerals. The color is not such as results from weathering in this climate and moreover it is impossible to suppose that so thorough oxidation of so dense and impervious a clay could have occurred since its deposition. The clay was evidently derived from red beds, or coloring matter was introduced into it during its deposition. Very little red material is included in the sheet of till deposited previously in this area, so that some new ingredient appears to have been introduced. Red drift was carried southwestward into Minnesota from the Lake Superior basin. When the Lake Superior Glacier was melted back eastward along the basin a temporary glacial lake, Lake Duluth, was held in the western end of the basin at such an altitude as to discharge across the divide to St. Croix River. The elevation of this divide is stated by Leverett [1] to be 1,013 feet above sea level, or about 373 feet higher than the Glenwood beach of Lake Chicago. When the ice front was receding eastward and the lake was being extended red silts were deposited in the Superior basin.[2] When the continued recession of the ice opened a lower (and lowering) outlet across the Upper Peninsula of Michigan to the Lake Michigan basin, there must have been a vigorous flow first to the Green Bay trough along the west margin of the ice sheet and thence by way of the Fox River valley to the Wisconsin at Portage and finally to the Lake Michigan basin and the outlet at Chicago.[3]

It has been suggested by Chamberlin[4] that fine red silts derived from the glaciation of red-rock formations and deposited in the Lake Superior basin may have been swept southward with the strong flow of water from the upper lake basin and have found settling basins in the Green Bay trough and the lower parts of the tributary valleys and in the Lake Michigan basin. The red material might in such a way be thoroughly commingled with drift deposited in the lake from the west front of the contracted Green Bay and Lake Michigan glaciers.

These commingled deposits dropped in the lake basin would probably be in large part in the form of till. Some of the material may have been dropped as berg till by ice floating out from the glacier. Some of it would be assorted and laminated by the lake waters. Such parts of the area north of Milwaukee as had sufficiently low elevation would be submerged by the waters of Lake Chicago, and over such submerged tracts laminated clays and berg till would be laid down.

The distribution of the red pebbly clay till over the stratified deposits can be satisfactorily explained only as the result of a readvance of the Lake Michigan Glacier southward to the vicinity of Milwaukee and its crowding laterally upon the land to the west limit and terminal moraine of the red till as mapped, and of a simultaneous readvance of the Green Bay Glacier southward along the Green Bay-Lake Winnebago trough to the south part of Fond du Lac Township and its crowding laterally against and over the crest of the Niagara dolomite escarpment on the east.

Such a glacial readvance would probably have carried up from the lake bottom considerable red clay and have deposited it upon the stratified deposits; or, if the glaciers were previously carrying red drift its deposition would be continued upon the area that is now land.

This readvance of the Lake Michigan Glacier is believed to have been correlated with a similar readvance of the ice in the Lake Huron basin, where the limit is marked by the main moraine of the Port Huron morainic system. This morainic system (Pl. XXIII, p. 208), whose formation followed the Lake Arkona stage of Taylor, has been traced by Leverett and Taylor[5] around the lower peninsula of Michigan and southward on the east side of the Lake Michigan basin to the vicinity of Muskegon, nearly opposite Milwaukee, where it is cut off by the lake shore.

A study of the United States Lake Survey charts shows that the part of the lake basin between Milwaukee, Wis., and Grand Haven, Mich., is much shallower than that between Racine, Wis., and Holland, Mich. East of Mil-

[1] Leverett, Frank, Outline of history of the Great Lakes: Michigan Acad. Sci. Twelfth Ann. Rept., p. 28, 1910.

[2] Irving, R. D., Geology of the eastern Lake Superior district: Geology of Wisconsin, vol. 3, pp. 211-214, 1880. Sweet, E. T., Geology of the western Lake Superior district: Idem, pp. 355-356.

[3] Martin, Lawrence, The Pleistocene, in The geology of the Lake Superior region, by C. R. Van Hise and C. K. Leith: U. S. Geol. Survey Mon. 52, pp. 444-446, 1911.

[4] Personal communication to the writer.

[5] Leverett, Frank, and Taylor, F. B., The Pleistocene of Indiana and Michigan and the history of the Great Lakes: U. S. Geol. Survey Mon. 53, pp. 293-315, 1915.

waukee the lake bottom is everywhere at least 200 feet above sea level, but opposite Racine it is at sea level. This line between Milwaukee and Grand Haven seems to mark nearly the summit of the ridge between the two basins, both of which, with the dividing ridge, are covered by the lake. Although its composition and origin are unknown, the ridge may consist, in part at least, of morainal deposits of one of the later stages of glaciation and may possibly mark the limit of the readvance of the glacier at this stage.

The moraine terminating near Muskegon on the east side of Lake Michigan is said by Leverett not to contain red clay, although a red till from Manistee northward both overlies and contains laminated red-silt deposits. If the red silt was brought, as predicated, into the Lake Michigan basin from the Lake Superior basin by waters flowing southward toward the Chicago outlet along the west side of the contracted glacier the red material might not at first have spread to the east side of the basin. Even on the west side of the basin the red silt has not been found commingled with the lacustrine deposits south of the vicinity of Racine.

The readvance is believed to have taken place while yet the waters of Lake Chicago stood at the Glenwood shore line. The stratified deposits underlying the red till (see p. 311–313) are thought to have been laid down in large part as beach deposits along the Glenwood shore. When the ice readvanced the lake waters were crowded back, and the lacustrine deposits were covered with the red till. When the glacier again shrunk away the waters, still standing at this level, extended northward, submerging such parts of the red clay area as lay below the water level. No trace of the Glenwood beach remains between Wind Point, in Racine County, and Belgium Township, in northern Ozaukee County. From Belgium Township northward into Centerville Township in southern Manitowoc County what appears to the writer to be the Glenwood shore line is very faintly developed, yet traceable, at approximately the same level as in Racine County, along the west limit of a gently sloping flat plain or lake terrace, beyond which the surface of the drift rises more rapidly to the crest of the east ridge of the red-clay series. The slight development of beach phenomena on the surface of the red till is such as would be expected if this shore line was occupied only during the time required for the recession of the ice front to the north end of the basin, where the opening of an outlet lower than the Chicago outlet drew the lake waters down to a lower level.

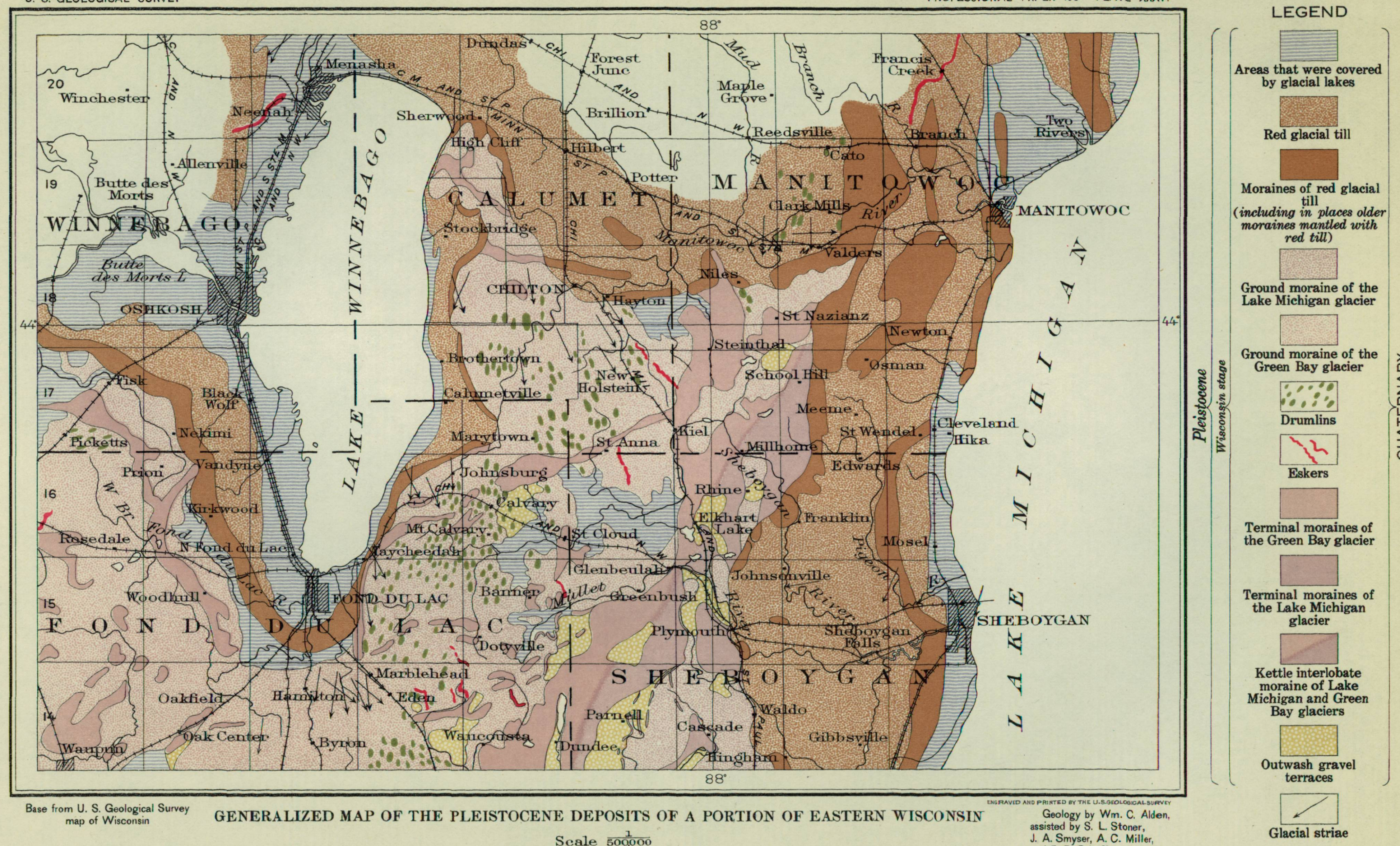
In the conditions afforded by the final melting of the Lake Michigan Glacier from this area is found an explanation of the gentle parallel ridging of the red pebbly clay similar to that in the drift ridges of the Lake Border morainic system. (See pp. 301–304.)

Extending southward from the valley of West Twin River, near the west line of Two Rivers Township, Manitowoc County, to Manitowoc and thence near the lake shore through Newton Township into Centerville Township (T. 17 N., R. 23 E.), is a slight moraine which appears to mark a position of the ice front after its recession into the lake basin farther south. This terminates just north of Fisher Creek, about 2½ miles northeast of Cleveland, near the north limit of the area in which the Glenwood waters encroached on the land. The plain, which is traversed by the railway west of this moraine, northward to and beyond Manitowoc River, is in part slightly undulating but is mostly nearly flat. It was probably submerged in part, at least, by marginal glacial waters, but being a little higher than the plain south of Fishers Creek was not covered by the standing waters of the lake.

Part of the surface of this moraine is but little if any above the Glenwood level, yet it is marked by slight sags and swells and does not appear to have been submerged. From the vicinity of Calvin Creek southward through Newton Township to the vicinity of Northeim the low swells are of sand and gravel. As exposed in the lake bluff the sand and gravel are seen to be a superficial deposit 1 to 12 feet or so thick overlying the red till.

It is possible the lake level was lowered while the ice front stood at this moraine either by the opening of an outlet around the north end of the southern peninsula of Michigan or by a cut in a barrier in the Chicago outlet.

The next succeeding stage of the recession is not represented within the area under discussion but may, perhaps, be represented by the ridge of red till extending southward for some miles in the town of Mishicot, Manitowoc County, between the valleys of North and Johnson creeks and East Twin River. Between 1



Base from U. S. Geological Survey map of Wisconsin

GENERALIZED MAP OF THE PLEISTOCENE DEPOSITS OF A PORTION OF EASTERN WISCONSIN

Scale $\frac{1}{500,000}$

10 5 0 10 20 Miles

1917

ENGRAVED AND PRINTED BY THE U.S.GEOLOGICAL SURVEY

Geology by Wm. C. Alden, assisted by S. L. Stoner, J. A. Smyser, A. C. Miller, and E. R. Scheffel. T. C. Chamberlin, geologist in charge. Surveyed in 1908-10 and 2 miles southeast of the village of Mishicot the surface of this ridge lowers and gives place to a nearly flat, broad, sandy plain near or slightly below the Glenwood level. Two and one-half miles northeast of Manitowoc Harbor the clay banks along the shore give place to the low sandy shore. The lake bluff a short distance west of the east line of Manitowoc Township exposes the cross section of a ridge of red till which rises about 15 to 20 feet above the beach. The crest and slopes are overlain by red stratified lake clays, sandy clay, and sand, so that the ridge does not rise above the level of the plain to the north. On the west slope of the ridge stringers of till are intercalated between layers of stratified clay as though a glacial front had stood at this place and deposited the till forming the ridge while laminated silts were being deposited in lake waters bordering it on the west. It is possible this buried ridge may be the continuation of the red till ridge which, about 7 miles farther north, rises above the level of the lake sediments underlying the flat sandy plain. This interpretation, however, makes the ridge of red till cut through by the bluff section of later deposition than the dense red-brownish pebbly till at the base of the bluff farther southwest, and also later than the main sheet of red till west of Manitowoc and Sheboygan. The writer is by no means sure that such is the true relation. The red till ridge in Mishicot Township may perhaps be the northward continuation of the moraine south of Manitowoc. As the ice front receded from this position the lacustrine deposits covered the crest of the till ridge and filled in behind it on the east.

OUTWASH DEPOSITS.

A deposit, principally of sand and gravel, which appears to have been formed by glacial drainage at a late stage of the glacial occupation of the area borders Milwaukee River in the northern part of the Milwaukee district. This is a continuation of like deposits farther north in the same valley. Probably it was formed by the glacial waters escaping while the ice front stood at the west ridge of the red-clay area. In most of the excavations the material is gravel, coarse below and finer above, with the bedding dipping southward as in an alluvial deposit. One exposure near the bridge, about 2 miles northwest of Whitefish Bay station, shows 15 feet of gravels over 10 feet of red clay.

RED TILL IN MANITOWOC AND CALUMET COUNTIES.

From the northeastern part of Liberty Township (T. 18 N., R. 22 E.) the margin of the red till may be traced first southwestward and then westward for about 15 miles through the middle of the towns of Eaton and Charlestown (T. 18 N., Rs. 20 and 21 E.) to the vicinity of Chilton, beyond which (see Pl. XXXVI) it may be traced northwestward for about 11 miles to the north end of the bold dolomite-capped escarpment near Sherwood. This alignment indicates the development of a lobe of ice 15 to 20 miles in width on the Niagara dolomite upland between the Lake Michigan and Green Bay glaciers. The ice

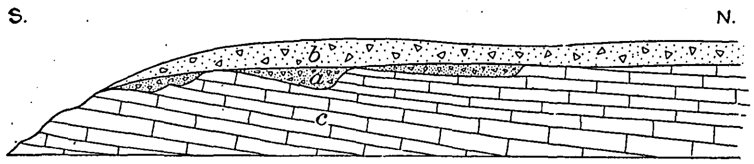


FIGURE 19.—Diagrammatic section of upper part of west face of Empire Lime & Cement Co.'s quarry, 2 miles west of Valders, Manitowoc County, Wis., showing relations of gray glacial till (*a*), red glacial till (*b*), and (*c*) Niagara dolomite.

overrode the Kettle interlobate moraine, the broad northward extension of the St. Anna moraine, and two small later moraines north of Chilton, and extended southward to within a mile or two of the north boundary of the area under discussion (latitude 44° N.). Certain other phenomena developed in the region immediately to the north within the area of this glacial lobe may be described in this connection as part of the evidence that the red drift was deposited during a readvance of the glaciers.

The quarry of the Empire Lime & Cement Co., about 2 miles west of Valders, is opened in the south end of a dolomite ridge. As shown by a north-south section at the west face of the quarry the beds dip northward at a low angle into the hill, their edges forming steplike projections beneath the thin coating of drift at the top of the south slope (fig. 19), leaving slight depressions in the lee (south) of the several lifts.

In these protected places there remains a thin deposit of the bluish-gray drift (*a*), like the main drift sheet outside the margin of the red drift. Overlying this and in places resting on the tread of the steps (*b*) near their front (south) edges is 4 to 5 feet of red till. The relation indicates that the surface of the dolomite was first left mantled with the blue-gray drift. Later, when the glacier readvanced, most of this drift was scraped off, excepting in the lee of the steps. The melting of this ice left the mantle of red drift lying in places on the dolomite and in places on the blue-gray till.

The most interesting feature noted is the fact that beneath the blue-gray drift, where undisturbed, the surface of the rock is glaciated with striæ bearing S. 38°–60° W. Where the glacier bearing the red drift scraped the blue-gray till off the top of the ledges and wore down the rock it obliterated some of the southwesterly trending striæ and graved new ones bearing S. 38°–52° E. in their places. Elsewhere it did not entirely wear away the earlier set and the two sets are found crossing. There is thus evidence not only of two distinct deposits of drift of different colors, but also of two successive ice sheets moving nearly at right angles to each other.

RED TILL IN THE LAKE WINNEBAGO AND FOX RIVER BASINS.

MARGIN OF THE RED TILL.

DISTRIBUTION.

About three-fourths mile northeast of High Cliff, on top of the 200-foot bluff, the margin of the red till turns sharply southwest and extends as a slight ridge about three-fourths mile to a point just above High Cliff. (See Pl. XXXVI.) From this point southward for nearly 4 miles, past the Stockbridge brickyards, the Green Bay Glacier appears not to have overtopped the high bluff; at least no red drift was seen on the upland above. North of the village of Stockbridge, in a reentrant in the escarpment, the bluff changes to a more moderate slope as it curves to the east and south of the village but again becomes marked as the dolomite ledge reappears. The readvancing glacier conforms to the sinuosities of the escarpment, and the margin of the red drift may be clearly traced about this reentrant at the top of the slope. There was thus a sharp reentrant nearly 9 miles deep between the contiguous fronts of the glacial lobe, which lay on the upland, and the Green Bay Glacier, which lay in the Winnebago Valley and barely overtopped the escarpment. At one point northeast of Stockbridge the two ice fronts advanced to within a mile of each other. Across this interlobate tract, which has an area of 20 to 25 square miles, two small but well-marked recessional moraines of the blue-gray drift may be traced. These emerge from beneath the red drift on the east. The more southerly one passes beneath the red drift on the west 2 miles southeast of Stockbridge and the more northerly one spreads out on top of the escarpment between 2 and 4 miles south of High Cliff. These mark stages in the recession of the ice from the St. Anna moraine and indicate the development of a similar lobe on the upland at that time.

To the south, through Stockbridge Township (Tps. 18 and 19 N., R. 18 E.), the marginal ridge of the red drift lies just on the edge of the upland above the escarpment and rises, in places, to 1,020 to 1,075 feet above sea level, or 200 feet higher than the crest of the red-till moraine on the plain south of Fond du Lac.

In Calumet Township the margin swings eastward about 5 miles and extends up a broad sag formed by a preglacial valley which cut the escarpment. Recurving again with the south side of this valley the slight marginal ridge, which has a relief of 10 to 20 feet, continues southward into Taycheedah Township (T. 16 N., R. 18 E.). At many places the red clay of this marginal ridge on the escarpment is higher than the surface of considerable tracts to the east, on which no vestige of the red clay has been seen. The topographic relations, together with the character of the deposit, place beyond question the interpretation that the red till is a glacial deposit made during a period of readvance of the ice front rather than a lacustrine deposit formed at a time of considerable northward depression and submergence. Between 1 and 2 miles north of Peebles the margin of the red drift gradually descends the slope, the ice to the south not having attained the crest of the escarpment. Here the railway ascends the escarpment over the heaped-up marginal deposit of red till. The railway cuts afford 20 to 30 foot exposures of the deposit.

Through the western tier of sections of Empire Township (T. 15 N., R. 18 E.) the red clay terminates at the foot of the slope which marks the line of the Niagara escarpment. The contact of the red and blue tills may be seen in the creek bank just north of the old flour mill in the NE. ¼ sec. 18. On the slope east of the convent the red till extends up to about 900 feet above sea level, or 150 feet above Lake Winnebago.

The south limit of the readvance of the Green Bay Glacier is marked by a low ridge or terminal moraine of red till which extends in a broad curve across the plain in the southern part of Fond du Lac Township. The flat plain south of Lake Winnebago rises gradually southward to the crest of this ridge at an elevation of 850 to 860 feet above sea level. From this crest, which is marked by slight sags and swells, the surface declines again southward 20 to 40 feet to Fond du Lac River and Neveu Creek, beyond which the plain again rises gradually to the foot of the Niagara escarpment. The red clay does not end abruptly at the morainal ridge but thins out to an indistinguishable margin 1 to one-half mile south of the morainal crest, thus barely extending into T. 14 N., R. 17 E. (Byron Township), on the south. The moraine and adjacent plain are cut through by a flat-bottomed valley 40 to 60 rods in width, through which Fond du Lac River meanders and from which abrupt marginal slopes rise 20 to 50 feet. The drift exposed in these slopes is moderately stony red till containing limestone and crystalline bowlders some of which are 2 feet in diameter. It is identical in character with that bordering Lake Michigan. At one point in the upper half of the section 10 feet of stratified sand and fine gravel is exposed. In the northern part of sec. 27, Fond du Lac Township, east of the railway the blue-gray till begins to rise above the water level as the red clay thins southward. Near the bridge in the SE. ¼ sec. 33 only 10 feet or less of red till overlies the blue-gray till. At these places the red till overlies the blue-gray till with no intervening stratified beds of clay, sand, or gravel.

After extending in a broad curve westward through the south part of Fond du Lac Township, indicating a symmetrically rounded southern extremity to the ice lobe, the red-till moraine extends in a nearly direct line somewhat west of north through the northeastern part of Lamartine Township and the central part of Eldorado Township to a point just west of the middle of Nekimi Township (T. 17 N., R. 16 E.), Winnebago County. Throughout this distance the moraine is a well-defined ridge about a mile wide that rises 40 to 60 feet above the marshy flats which border it on the west and above the nearly flat plain on the east. Its topographic prominence in this region of slight relief is indicated by the fact that the road traversing its crest through much of this part is known as the "ridge road." The notable difference in the character of the soil along it and east of it, as compared with that to the west, is a matter of common knowledge among the farmers of the region.

In the town of Nekimi the moraine swings to a more westerly trend and continues its ridge character through the northern part of the town of Utica to near Waukau, where it is crossed by the Chicago, Milwaukee & St. Paul Railway and is cut through by a creek valley. Two miles west of Waukau the ridge lowers, probably being swallowed up in filling a deep preglacial valley. East of Eureka the red drift is banked against or upon the ridge of Lower Magnesian limestone. Beyond Eureka the west side of the Green Bay lobe at this stage protruded along the Fox River valley to a point about a mile west of Berlin, whence the margin extended northward across the Fox and Wolf river basins.

CHARACTER.

That a considerable amount of red drift was absorbed in filling the preglacial valley of Fox River is indicated by a well on the lower ground about one-fourth mile north of the limestone ledge exposed in the north slope of the hill east of Eureka, which penetrated 116 feet of red drift to sand without reaching rock. It is not known, however, that the entire thickness of red drift is to be referred to morainal deposition; some of it may represent aqueous deposition in advance of the ice or at an earlier stage of glaciation.

A mile south of Eureka an excavation near the cemetery exposed 8 to 10 feet of pinkish sandy clay till, very stony in part. It is, however, different in character from the typical red till and is thought to be of different origin, the ice being thought not to have extended so far south during this stage. Three miles southeast of Eureka a road cut in the NE. ¼ sec. 7, T. 17 N., R. 14 E. (Nepeuskun Township), showed masses of red clay kneaded into the grayish till, as though red material from an earlier deposit had been incorporated into the gray till at an earlier stage of glaciation. In this connection it should be noted that one of Mr. Jordan's wells near this cut penetrated red sandstone beneath 48 feet of drift, though the other a few rods distant encountered limestone underlying the glacial deposits. The red material of the drift outside the red-till moraine is very local in its exposure and may be of local derivation.

The west branch of Fond du Lac River crosses the moraine in sec. 13, Lamartine Township, and sec. 18, Fond du Lac Township (T. 15 N., Rs. 16 and 17 E.), cutting through the whole thickness of the red drift (about 25 feet) and exposing very stony bluish-buff till. The red till is much less stony than the bluish till, is dense and compact, cracking into little blocks when dry rather than crumbling loosely. There can be no doubt, however, that it is glacial till. Its upper part, as seen in the exposures, is bleached to grayish but is shown by tests with acid to contain much calcareous material below a depth of 1½ to 2½ feet. At Waukau the slopes of the valley, now 30 to 40 feet in depth, show that the material of the ridge is dense, unstratified, moderately stony, highly calcareous red-clay till, like that exposed in more surficial cuts all along the moraine. A thorough examination was not made of the whole section, which is much obscured by slumping and is largely overgrown by vegetation.

Thicknesses of 20 to 70 feet of red drift above the bluish till are reported from wells along this moraine, so that it appears that the relief of the ridge is due to marginal thickening of the sheet of red drift.

The surface of the red-till moraine is in general smoothly undulating, being interrupted in only a few places by sags and swells such as characterize other moraines. Red clay, probably deposited in the bordering ponded waters, was noted underlying the black soil on the flats outside this moraine and extending, in southwestern Fond du Lac Township (T. 15 N., R. 17 E.) at least a mile beyond the moraine front. Where the moraine is bordered by undulating tracts the margin of the red drift is remarkably distinct, being usually plainly discernible in the roads and cultivated fields. Except for silts deposited in local bordering lakes no lacustrine deposits are visible. The red-drift border, far from resembling an ancient shore line, consists of a definite bulky terminal moraine, piled in a ridge which throughout a large part of its extent rises well above the red-till plain on the inside and above the marshes and undulating ground moraines of the bluish till immediately on the outside.

In the southwestern part of Fond du Lac Township (outside the moraine) an exposure of 1 foot of black humus and 3 feet of whitish-gray clay containing small shells overlying the red clay indicates an old marsh that has been drained by Fond du Lac River. This marsh was probably the closing stage of a glacial lake which bordered the ice front as it stood at the red-till ridge in southern Fond du Lac Township, and which discharged across the low divide to Lake Horicon and Rock River at about 863 feet above sea level. With the retreat of the ice front and the opening of the Fox River valley the waters cut through the red-till ridge, excavating the valley of Fond du Lac River and draining the lake northward to the Lake Winnebago basin.

The water level was probably lowered slowly so that the stream meandered and widened the channel through the moraine. Bryant Walker, of Detroit, Mich., to whom specimens of the shells collected from the whitish clay noted above were referred, recognized *Sphærium simile* Say, *Pisidium* sp.?, *Amnicola limosa* Say, *Valvata tricarinata* Say, *Planorbus parvus* Say, and *Planorbus bicarinatus* var. (approaching var. *portagensis* Baker). He states [1] that the shells are like others found in Michigan and do not differ from recent forms of the species. To his list W. H. Dall[1] adds *Sphærium sulcatum* Lamarck.

After the ice front had melted eastward beyond Waukau the waters ponded over the big marsh area within the St. Anna moraine found outlet to the Fox across the red-till

[1] Personal communication.

moraine just east of Waukau. Later the waters in Rush Lake basin similarly notched the red-till moraine to the northeast and drained to the Fox.

RED-TILL SHEET WITHIN THE MORAINE.

Within the terminal moraine described above the red-drift sheet declines gently to the shore of Lake Winnebago. The bulk of this deposit appears to be glacial till like that of the moraine; at least this is true of the material seen in exposures, very little stratified red drift being seen at any place. The cut where the electric railway crosses under the steam railways near Anderson Creek north of North Fond du Lac exposes 15 feet of stony red till with no evidence of stratification. A sample of the unweathered till for analysis was taken at this place. As exposed at the stone quarries in the southwestern part of Oshkosh, just north of the boundary of this area, the red till is very thin, ranging from 1 to 5 feet in thickness over 1 to 10 feet of very compact and stony buff-bluish till. At one point a foot of laminated red clay was observed between the red till and the underlying buff till; elsewhere no stratified drift was noted. Samples of the weathered red till, of the unweathered red till, and of the underlying buff till were taken at Robert Lutz's quarry for analyses and comparison. (See p. 322.)

The part of the plain lying above the 800-foot level has the topography of a very gently undulating ground moraine, and the part lying below 800 feet is nearly flat.

In general the wells on the plain seem to penetrate rather less red till than those in the terminal moraine. The average thickness found in 41 wells on both plain and moraine is about 33 feet, the range being 1 to 70 feet.

William Sealey, a well driller of Fond du Lac, informed the writer that at Fond du Lac he has generally found, beneath the red clay, 3 to 4 feet of very stony greenish clay underlain by a less stony blue clay; and that, on the Fond du Lac plain, he has often encountered black material at depths of 30 to 50 feet. These are probably remains of an old soil and vegetation which grew in the interval after the melting back of the Green Bay Glacier following the deposition of the blue-gray till and prior to the readvance of the glacier depositing the red till.

A well at the Nash farm, in the NE. ¼ sec. 3, T. 16 N., R. 16 E. (Eldorado Township), is said to have encountered leaves and other vegetable material beneath 35 feet of red drift. A driller of numerous wells in the eastern part of the Nekimi Township and the western part of the adjacent Black Wolf Township informed the writer that in several he encountered "black muck" beneath 14 to 20 feet of red drift. From his description, however, there is some doubt as to whether this contained vegetable material like marsh muck. In view of the occurrences reported by Mr. Sealey from the vicinity of Fond du Lac it appears that these may represent a soil horizon developed during the interval of exposure of the bluish till prior to the deposition of the red drift.

At a few places sand or gravel was reported to have been penetrated between the red and the blue tills.

COMPOSITION OF THE RED DRIFT.

MECHANICAL ANALYSES.

Examination of the pebbles included in the red drift at 15 different places, mostly in Sheboygan and Manitowoc counties, with two in Milwaukee County and one in Fond du Lac County, showed percentages somewhat different from most of these of the blue-gray till, the red drift containing a larger average percentage of foreign material. This difference, however, is not thought to be an essential one.

Estimate of pebbles in the red till.

	Per cent.
Devonian	4.0
Niagara dolomite	77.6
Sandstone	1.0
Crystallines	16.4
Chert	1.0

For more careful comparison as to constitution and probable derivation the writer collected samples of the red drift and of the buff-bluish underlying till sheet and had analyses made to show their physical characters and their chemical composition. For this purpose only the finer material was used after the removal of particles larger than 1 millimeter in diameter. Through the kindness of J. A. Bonsteel and his associates on the soil survey, Bureau of Soils, Department of Agriculture, mechanical analyses were made of eight samples, as shown in the accompanying table.

A comparison of the results presented in the table shows striking similarity between the texture of the red clay and that of the typical glacio-lacustrine silt from Delton Township. Of the latter (analysis 1) 3.6 per cent of the constituent particles were larger than 0.05 millimeter and 96.3 per cent was graded as silt and clay finer than 0.05 millimeter. Of the red till (2) 20 per cent was coarser than 0.05 millimeter and 80 per cent was silt. Of the red till (3) 6.7 per cent was coarser than 0.05 millimeter and 93.3 per cent was silt. It is thus evident that the matrix of the red till is very largely silt, comparable to a glacio-lacustrine silt.

The analyses of samples of the buff or bluish till of the underlying and more extensive drift sheet show very different textures. Analysis 4 shows 62.5 per cent as coarse as fine sand (0.05 millimeter or coarser) and 38.3 per cent silt; and analysis 5 shows 56.8 per cent coarser than 0.05 millimeter and 43.3 per cent finer. The contrast is even more striking if only the percentages of very fine clay (diameter 0.005 millimeter or less) are considered. Of this, analysis 1, lacustrine clay, contains 46.9 per cent; 2, red till, 41.3 per cent; 3, red till, 51.5 per cent; 4, buff till, 8.2 per cent; 5, buff till, 7.6 per cent. It should also be stated that the texture of the red till, so far as can be seen megascopically and as appears from its tenacity when wet and its hardness when dry, is practically identical over the whole area of about 1,000 square miles examined by the writer in the Winnebago and Fox River valleys and along the west shore of Lake Michigan.

Mechanical analyses of lacustrine clay, glacial till, and loess.

[Analyses by Bureau of Soils, U. S. Department of Agriculture.]

No.	Locality.	T. N.	R. E.	Sec.	Description.	Fine gravel (2-1 mm.).	Coarse sand (1-0.5 mm.).	Medium sand (0.5-0.25 mm.).	Fine sand (0.25-0.1 mm.).	Very fine sand (0.1-0.05 mm.).	Silt (0.05-0.005 mm.). Coarse.	Silt (0.05-0.005 mm.). Fine.	Clay (0.005-0 mm.)
	Sauk County.												
1	Delton Township	13	6	6	Typical glacio-lacustrine reddish laminated silt.	0.0	0.1	0.0	0.4	3.1	13.9	35.5	46.9
	Fond du Lac County.												
2	Friendship Township	16	17	29, NE. ¼	Unweathered red glacial till from railway cut.	1.1	3.0	1.8	5.3	8.8	15.4	23.2	41.3
3	Lamartine Township	15	16	13, SE. ¼	Unweathered red glacial till from terminal ridge.	.5	1.1	.8	1.9	2.4	13.3	28.5	51.5
	Winnebago County.												
4	Oshkosh, southwest part	...	...	...	Buff glacial till from beneath red till in Lutz's quarry.	6.5	9.4	6.7	20.0	19.9	19.8	10.3	8.2
5	Nekimi Township	17	16	31, SW. ¼	Buff glacial till from 2 miles west of red-till margins.	3.0	8.4	6.4	18.9	20.1	25.4	10.3	7.6
	Crawford County.												
6	Bridgeport Township	6	[a]6	...	Loess [b]	.0	.0	.0	.7	19.6	50.0	14.8	14.7
	Columbia County.												
7	Fountain Prairie Township.	11	12	28	do	.0	.0	.2	1.0	5.1	62.6	18.9	12.2
8	Driftless Area	...	...	...	Composite of loess loams. [b]	.1	.1	.1	1.7	18.2	47.1	16.0	16.4

[a] Range west.

[b] See p. 345.

From the analyses it is evident that a very large part of the red till is silt and clay of such fineness that it might be transported long distances in suspension in water of no great velocity of flow. It should also be noted that the samples of red till were taken from below the zone of evident leaching and oxidation (from 1½ to 2½ feet in this till sheet), so that the particles have not been further comminuted by weathering since their deposition

OXIDATION.

It has been suggested to the writer that the red till is but the weathered portion of a sheet of bluish till, the red color being due to oxidation of the ferruginous constituents since its deposition. It is undoubtedly true that the iron of the red till is more highly oxidized than that of the other till, whose color, except in a very superficial zone (where it may be brownish, but is never orange or red), is rarely deeper than a very light buff. The writer contends, however, that the red color of the red till is not due to oxidation since deposition but is due to the introduction of a very fine red silt. The deposit is so dense and so difficultly pervious that water passes through it only very slowly; yet the red color persists with practically uniform tint throughout thicknesses of 50 to 100 feet. The effect of such weathering as has taken place has been the leaching out or bleaching out, perhaps by vegetal acids, of the upper few inches or 1 foot to a dirty grayish color.

The chemical analyses which follow, made by W. T. Schaller, show that the most readily soluble constituents—that is, the calcium and magnesian carbonates—are present in even greater percentages in the unweathered red till than in the immediately underlying buff till. They have been partly removed only from the thin superficial zone which has evidently been leached and oxidized since deposition. It seems to the writer impossible that bluish calcareous till of such density as the red till should retain the soluble carbonates throughout, with the exception of this very thin superficial zone, and yet have been exposed long enough to be oxidized to so uniform and pronounced a red color throughout thicknesses of 25 to 100 feet. Not only is much carbonate present throughout the red till, but the dolomite pebbles have not even had their surface etched by solution. In discussing the effects of weathering on the Illinoian till it was noted (p. 157) that at many places in the northern counties of Illinois the light color of the unweathered till had been changed to brick red by oxidation in a superficial zone a few feet thick, but it was also noted that in this zone the leaching had been so thorough that not only the soluble parts of the fine calcareous rock flour but also all limestone pebbles up to several inches in diameter had been removed, and that at the bottom of this zone etched and rotten limestone pebbles showed a gradation through a zone of less than a foot to unaltered highly calcareous till. Nothing at all comparable to this has been observed anywhere in the area of the red till examined by the writer.

Chemical analyses of glacial till and lacustrine clay.

[W. T. Schaller, analyst.]

	1 Red till (unweathered).	2 Red till (leached and oxidized).	3 Buff till.	4 Red till (unweathered).	5 Glacial lake red clay.
SiO_2	43.20	56.58	41.84	42.76	40.56
Al_2O_3	11.42	14.22	7.90	12.28	14.91
TiO_2	.59	.77	.49	.56	.57
Fe_2O_3 (total iron)	4.36	6.81	2.86	4.27	4.32
MgO	6.07	3.48	7.03	3.09	2.63
CaO	11.54	2.88	14.43	12.81	12.11
K_2O	2.46	3.44	1.46	2.48	2.57
Na_2O	1.50	1.41	1.64	1.78	1.59
CO_2	14.80	2.51	6.82	15.54	2.24
H_2O	4.56	8.00	15.10	4.79	18.30
	100.50	100.10	99.57	100.36	99.80

1. Red glacial till from Robert Lutz's quarry in the southwest part of Oshkosh, Wis.; sample taken 2 to 3 feet below the surface, below the zone of leaching and oxidation and above the buff till.
2. Red glacial till from Robert Lutz's quarry in the southwest part of Oshkosh, Wis., leached and oxidized; sample taken 2 feet from the surface, just below the grayish humus soil.
3. Buff glacial till from Robert Lutz's quarry in the southwest part of Oshkosh, Wis.; till very compact and hard; sample taken 6 feet below the base of the red till (No. 1).
4. Red glacial till from sec. 24, T. 14 N., R. 7 E. (New Haven Township), Adams County, Wis., northwest of Briggsville, Wis.; sample taken below the zone of weathering.
6. Glacial lacustrine clay from sec. 6, T. 13 N., R. 6 E. (Delton Township), Sauk County, Wis.

The red till clearly overlies the bluish-buff till sheet which was deposited by the glaciers of the later Wisconsin substage; and observation of this drift over thousands of square miles beyond the limits of the red-till area shows that it has been only very superficially modified by leaching and oxidation since its deposition. The stratigraphic relations and the conditions of deposition by the glaciers forbid any suggestion that the bluish till found beneath the red till is not the same as that exposed beyond its limits.

Some deposits of red clay (see p. 166) that are exposed in the lower part of the bluff along the shore of Lake Michigan near Milwaukee are probably of pre-Wisconsin age, but these clearly do not belong to the red-till sheet here under discussion. In the collection of samples for analyses and comparison the stratigraphic relations must be understood and care must be used that the samples really represent the drift sheets that are being considered. The writer has not had analyses made of the lower red pebbly or laminated clays exposed near Milwaukee, but he interprets certain analyses which may possibly represent these older deposits as he has those given above, and he does not at all agree with the idea that the red color of these dense highly calcareous clays is due to oxidation since their deposition by Pleistocene glaciation.

GLACIAL LAKE IN THE WINNEBAGO AND FOX RIVER VALLEYS.

At intervals northward from sec. 6, T. 15 N., R. 18 E. (Empire Township), through Taycheedah, Calumet, and Brothertown townships an ancient lake beach marks a stage, following the melting back of the front of the glacier which deposited the red till, when the Winnebago basin and adjacent plain were submerged beneath waters held up by the retreating ice front. From Calumet Harbor northward through Brothertown the military road runs along the ridge of these beach gravels, which are exposed in numerous small excavations. From one pit, that of J. C. Huber, 3 miles east of Fond du Lac, in sec. 7, Empire Township, gravel is obtained for use in Fond du Lac. Here, as in some other excavations, characteristic beach structure is to be seen in the well-assorted and stratified gravels. Where the gravels are not present there is a more or less well defined cut bank at approximately 800 feet above sea level, in which the gravels occur principally between 800 and 810 feet.

At intervals at the same elevation about the south and west sides of the basin in Fond du Lac, Friendship, and Black Wolf townships (Tps. 15–17 N., R. 17 E.), a beach is slightly developed and stratified gravels are exposed in many small excavations. The stronger development of the beach on the east side of the basin was probably due to prevailing southwesterly winds which then as now caused stronger wave action along the east shore.

Between 3 and 4 miles north of Vandyne, in secs. 13 and 18, Black Wolf Township, east of the railways, an excavation in a low hill exposes stratified gravel and some sand with bedding dipping southward. The gravel is mostly coarse and resembles a morainal deposit rather than beach gravel. On the slope at about the 800-foot level the gravels are finer and contain some intermingled red clay, as though worked over by the lake waters. In the southern part of Algoma Township (T. 18 N., R. 16 E.), near the north line of the area under discussion, the lake shore extended westward into the Fox River valley and followed a sinuous course to the vicinity of Eureka. At a few places near the 800-foot elevation there are slight deposits of stratified gravels but no definitely marked shore line. Above this level the surface is gently undulating. West of this line in Fond du Lac County and south of it in Winnebago County the surface is gently undulating and rises gradually 50 to 60 feet to the crest of the red-till moraine. Below this level the plain is nearly flat.

The water level shown by this ancient beach is but slightly higher than the portage across the marshes between Fox and Wisconsin rivers at Portage, where the Wisconsin is 787 to 796 feet above the sea. There can be little question, therefore, that this ancient beach marks the elevation at which waters were ponded for a considerable time after the ice front had retreated so as to open an outlet by way of Fox River valley to the Wisconsin. The water must have assumed this level as soon as the ice cleared the Fox River valley and have continued thus until the farther melting of the ice opened a lower outlet across Door Peninsula to Lake Chicago, which occupied the Glenwood shore line in the Lake Michigan basin at about 640 feet above sea level. On the east this glacial lake was limited by the steep slope of the Niagara escarpment, and south and west of Fond du Lac by the red till ridge. The site of Fond du Lac was thus submerged beneath 40 to 60 feet of water. The upper part of the ridge just south of Eureka, as well as other ridges between Fox River and Lake Poygan, in Rushford and Poygan townships, must have stood as islands in the lake. Farther west and southwest, in Waushara and Marquette counties, the waters submerged much of the lowlands now occupied by the extensive marshes. North and west of Oshkosh the lake waters extended far up the valleys and spread widely over the intervening lowlands, submerging considerable parts of Marinette, Shawano, Brown, Outagamie, Waupaca, Winnebago, Green Lake, Marquette, and Columbia counties.

This is the glacial lake which Upham named "Glacial Lake Nicolet" in 1903.[1] In this paper Upham adopts Chamberlin's earlier interpretation that the red clay was deposited in the waters of a great lake formed during a stage of considerable northward depression, but he postulates a glacial barrier on the north and modifies the interpretation of the character of the red clay. He says:[2]

> From my detailed examinations of glacial Lakes Souris, Agassiz, and Duluth, it seems to me quite certain that the red clay described by Chamberlin, as quoted before, is not an ordinary lacustrine sediment, in the sense of being brought by tributary streams or supplied through erosion from the shores and bed of the old lake by its wave action, but rather that this deposit consists of englacial drift which here was received into the water of the glacial lake. By lacustrine action it was somewhat stratified and assorted, but by its inclusion of frequent rock fragments, it yet retains generally, as I think, more of the features of till than it has acquired of the usual character of water-laid drift. * * * If Lake Chicago at any time fell below the Chicago outlet, it must, in my opinion, have then outflowed by the way of Portage to the Wisconsin River.

His opinion as to Lake Chicago appears to have little foundation in fact, as the highest beach leading into the Chicago outlet is 640 feet above sea level and the divide at Portage is approximately 797 feet above sea level, and as, furthermore, so far as present studies on the ancient shore lines of the upper Great Lakes have progressed, such northward depression as did occur was limited almost entirely to areas north of the latitude of Portage and probably did not affect the relative elevation of this outlet. As shown by the preceding discussion the red clay in eastern Wisconsin is principally glacial till and its distribution was due to a readvance of the glaciers with some associated aqueous deposition within the limits of the bordering glacial lakes and streams; and the altitudes attained by the deposit indicate not the extent of northward depression and submergence but the relative heights to which it was carried by the readvancing ice. If the name Glacial Lake Jean Nicolet is to be retained for the glacial lake discharging across the divide to Wisconsin River at Portage it should be used only for the lake having the elevation and extent described in this present paper. Personally, the writer would prefer the use of some other name, owing to the confusion that would be likely to arise through a change in application, and also owing to the previous use of the name Nicolet by Winchell[3] for a glacial lake which he believed to have covered the sites of Leech, Winnibigoshish, and Cass lakes, in Minnesota, near the source of Mississippi River, a use that led Upham to change the name proposed for the lake discharging at Portage from Nicolet to Jean Nicolet.[4]

The black humus layer that covers the red till on the Fond du Lac plain was probably developed by marshy conditions which accompanied the draining of the glacial waters from the lowlands.

Glacial lakes of similar extent, discharging by the same outlet to the Wisconsin at Portage, were undoubtedly developed in connection with the earlier melting of the Green Bay Glacier and again in connection with the readvance of the ice at the stage of deposition of the red till; and in these lakes, the predecessors of the one just discussed, were probably deposited such assorted and stratified gravel, sand, and clay as are found intercalated between the red till and underlying blue-gray till. It is from these intercalated stratified beds that the first of the artesian flows is obtained in the area covered by this ancient lake. The deeper flows come from sands and gravels included in or buried beneath the blue-gray till of the pre-Wisconsin or from the deeper-lying limestones and sandstones.

[1] Upham, Warren, Glacial Lake Nicolet and the portage between Fox and Wisconsin rivers: Am. Geologist, vol. 32, p. 105, 1903.
[2] Idem, pp. 113-114.
[3] Winchell, N. H., Geol. Soc. America Bull., vol. 12, p. 122, February, 1901.
[4] Upham, Warren, Glacial Lake Jean Nicolet: Am. Geologist, vol. 32, p. 330, 1903.

CHAPTER XI.—GLACIAL LAKE DEPOSITS AND HISTORY.

GLACIAL LAKE CHICAGO.

SHORE LINES.

When the Lake Michigan Glacier was melted back from the crest of the Valparaiso morainic system water began to be ponded between the ice front and the moraines (p. 310). A lake, called glacial Lake Chicago by Leverett,[1] was thus initiated in the south end of the basin even before the ice front in southeastern Wisconsin had retreated to the position of the west ridge of the Lake Border morainic system. The water thus ponded found an outlet across the crest of the moraine at a low point southwest of Chicago and by erosion developed the valley known as the Chicago outlet, now traversed by the Des Plaines River. The character and history of this outlet and of the associated lacustrine phenomena have been described by numerous writers,[1] most recently and most in detail by Leverett, Taylor, Salisbury, Alden, Atwood, and Goldthwaite.

From the State line northward throughout the Wisconsin lake-border region the ancient shore lines have been studied and described by J. W. Goldthwait,[2] who carefully measured the elevations of the several beaches at many places in order to determine whether or not they had been subjected to deformation by uplift. The present writer's studies have extended northward to the vicinity of Two Rivers, Wis., but all his measurements have been made by aneroid readings either from the present beach or from railroad elevations. Some of his observations were furnished to Goldthwait and others have been published by himself.[3] Earlier studies by Chamberlin[4] did not correlate the several beaches in eastern Wisconsin with those in other parts of the Lake Michigan basin.

GLENWOOD STAGE.

GLENWOOD BEACH.

GENERAL FEATURES.

The first and highest level of glacial Lake Chicago definitely marked by a shore line is about 636 feet above sea level, or 50 to 55 feet above Lake Michigan. The beach formed at this level has been designated the Glenwood beach by Leverett from its strong development at Glenwood, Ill., south of Chicago. As the ice front was melted back within the present limits of the lake and northward along the basin the lake gradually extended until it encroached on the borders of Wisconsin. (See fig. 20.) Between Winnetka and Waukegan the ancient beaches have been cut away by later encroachment of the lake, but from Waukegan northward through Kenosha and Racine counties to 3 miles north of Wind Point the Glenwood beach is preserved and is well developed. Thence northward through Milwaukee and Ozaukee counties no definite trace of this shore line remains. The surface bordering the lake shore is for the most part now too high to have been submerged. It is believed to have been lower north of Milwaukee prior to the deposition of the red clay, so that the Glenwood waters encroached on the land to distances varying from a mile to several miles. The stratified sand and clay described above as exposed in the lake bluff north of Bay View are believed to have been deposited in the littoral waters of Lake Chicago at the Glenwood stage. North of Milwaukee these deposits are overlain

[1] Leverett, Frank, The Pleistocene features and deposits of the Chicago area: Chicago Acad. Sci. Geol. and Nat. Hist. Survey Bull. 2, 1897; The Illinois glacial lobe: U. S. Geol. Survey Mon. 38, pp. 418–459, 1899.

Leverett, Frank, and Taylor, F. B., The Pleistocene of Indiana and Michigan: U. S. Geol. Survey Mon. 53, 1915.

Salisbury, R. D., and Alden, W. C., The geography of Chicago and its environs: Chicago Geog. Soc. Bull. 1, 1899.

Alden, W. C., U. S. Geol. Survey Geol. Atlas, Chicago folio (No. 81), 1902.

Atwood, W. W., and Goldthwait, J. W., Physical geography of the Evanston-Waukegan region: Illinois Geol. Survey Bull. 7, pp. 54–68, 1908.

Goldthwait, J. W., Correlation of the raised beaches on the west side of Lake Michigan: Jour. Geology, vol. 14, pp. 411–424, 1906; The abandoned shore lines of eastern Wisconsin: Wisconsin Geol. and Nat. Hist. Survey Bull. 17, 1907; A reconstruction of the water plains of the extinct glacial lakes in the Lake Michigan basin: Jour. Geology, vol. 16, pp. 459–476, 1908; Physical features of the Des Plaines valley: Illinois Geol. Survey Bull. 11, 1909.

[2] Goldthwait, J. W., Abandoned shore lines of eastern Wisconsin: Wisconsin Geol. and Nat. Hist. Survey Bull. 17, 1907.

[3] Alden, W. C., op. cit., pp. 68–72.

[4] Chamberlin, T. C., Geology of Wisconsin, vol. 1, 1883; vol. 2, 1877.

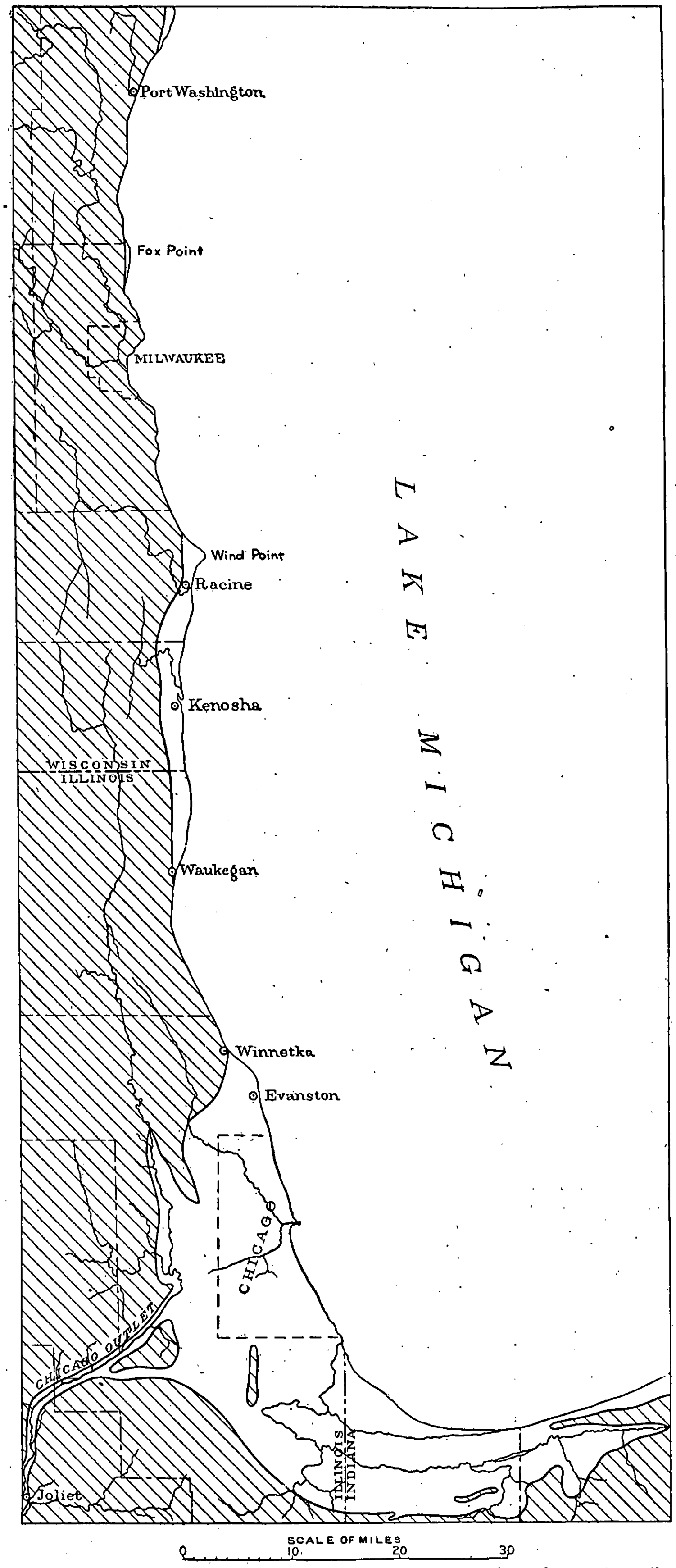


FIGURE 20.—Sketch map showing maximum extent of glacial Lake Chicago in southeastern Wisconsin, Illinois, and northern Indiana. Land areas and shore line, where preserved, indicated by shading.

by the sheet of red pebbly clay deposited in connection with a readvance of the Lake Michigan Glacier, which overrode the lacustrine deposits, forced back the lake waters, and encroached upon the land as far south as Milwaukee. North of Milwaukee, therefore, the original Glenwood shore line is supposed to underlie the red drift. With the recession of the ice front, however, the lake was again extended, and such parts of the red-drift sheet bordering the lake as were not too high were submerged. In Sheboygan County and southern Manitowoc County a nearly flat plain, extending westward to a higher undulating area is developed slightly below the Glenwood level and appears to have been submerged. Slight traces of a shore line and slight delta deposits indicate that when the ice depositing the red drift was melted back the water still stood at the Glenwood level. South of Milwaukee the Glenwood stage was continuous. North of this place there was an early Glenwood stage, then a stage of glaciation followed by a later Glenwood stage.

DISTRIBUTION AND CHARACTER.

From the State line northward to Racine the Glenwood beach lies 1¼ to 2 miles west of the present lake shore, marking the line between the lacustrine plain on the east and the gently undulating drift topography on the west. In the northwestern part of Racine the beach has been largely destroyed by subsequent erosion, but north of Racine it is well developed. For 3 miles it is traversed by the line of the Milwaukee, Racine & Kenosha Electric Railway. About 2 miles farther north it is intersected by the present lake bluff.

This beach is usually marked by a low ridge of sand and gravel with a relief of 5 to 20 feet on the east and less on the west. For about 2 miles southwest of Racine it has a double development, the inner ridge being slightly lower than the outer. The inner or eastern ridge has the form of a spit or hook (Pl. III, in pocket), and it was probably formed as a bar across the mouth of Root River by the southward drift of the beach sand and gravel and by the detritus brought down by the stream. With the lowering of the water level this ridge emerged and became the beach. For about 2 miles northwest of Kenosha the shore is marked by a terrace and low bluff cut in till. In the southern part of Pleasant Prairie there is an inner and an outer and higher beach ridge. The preservation of the ancient beaches in Racine and Kenosha counties is largely due to the outcropping dolomite at Wind Point, which has retarded the encroachment of the lake upon the land.

The elevation of the lower ridge is about 55 feet above Lake Michigan (636± feet above sea level); that of the outer ridge in places reaches 70 to 80 feet above the lake. Goldthwait found a similar double development southward nearly to Waukegan. The outer and higher ridge he thought possibly to have been developed in connection with the initial glacial marginal drainage before the ice had been melted sufficiently to allow the extension of the lake at the Glenwood level. At Waukegan, Ill., Goldthwait found the Glenwood beach 50 to 55 feet above the lake; at Zion City, Ill., 53 feet. For 6 miles or more it is followed by Sheridan Road. About a mile north of the State line the road leaves the upper beach and follows the one next lower. At the State line the highest beach ridge, as measured by Goldthwait, is 53 to 58 feet above the lake. On the Racine-Kenosha county line three closely set crests of the Glenwood beach were 53, 54, and 56 feet, respectively, above the lake.

The off-shore deposits correlated with the Glenwood beach are exposed in the lake bluff, and in the clay pits at several brickyards. These consist principally of fine stratified sand and laminated clays. For 3½ miles southeastward from the point of intersection of the Glenwood beach by the present lake shore to the apex of Wind Point the bluff section shows the following sequence of deposits from the top to the bottom of the bluff:

Lacustrine beds exposed in the lake bluff section.

	Feet.
Sand	0- 6
Laminated red and blue clay	9-20
Buff sand	0- 2
Stony blue till down to the beach.	

In places the upper sand is washed from the surface near the crest of the bluff, but back from the bluff to within half a mile to a mile of the Glenwood beach this upper sand is present. Much of it belongs to the second beach deposit. Below this sand are the laminated lacustrine clays, whose thickness varies with the undulations of the underlying till surface, in some places reaching 20 feet and in others disappearing entirely. The underlying thin bed of sand is also discontinuous and in places the laminated clay overlies the till. At one point in the lower part of the section there was exposed a dense brownish hardpan of contorted layers of interlaminated sand and clay which is thought to belong to the pre-Wisconsin drift deposit. The line between this hardpan and the lacustrine clay is sharp even where no sand layer intervenes, the upper surface of the hardpan being in places smooth as a glaciated rock surface. In digging the putty-like red clay peeled from the surface of the lower clay, leaving it perfectly clean and distinct. The red clay is well exposed in the clay pit of Hilker Bros.' brickyard, at Wind Point. At the brickyards just north of Racine 4 to 8 feet of laminated purplish red and blue clay occurs between the surficial sand and the underlying stony blue till. From Wind Point nearly to Kenosha lacustrine clays are usually present between the sand and the till in the bluff section, but in places, owing to inequalities of the till surface, the sand immediately overlies the till.

The lacustrine deposits are also well exposed in the clay pit at W. J. Craney's brickyard, about a mile northwest of Kenosha.

Lacustrine beds exposed at W. J. Craney's brickyard.

	Ft.	in.
Leached clay	3	0
Brownish laminated clay	2	0
Clayey sand		8–12
Dense, brown, calcareous clay		6–8
Stoneless blue clay, partly laminated, including 1 foot of blue sand	6	0
Blue gravel		2–3
Stony clay (till).		

The purplish-red color noted in the clay at Wind Point, Bay View, and in the main red-clay deposit from Milwaukee northward seems to fail south of Racine; at least no clay of this color was noted south of the latter place.

From the place 3 or 4 miles northwest of Wind Point, where the Glenwood beach is cut off by the present shore line, to the north side of the moraine northeast of Cudahy, a distance of 11 miles, the present shore lies farther west than the ancient beaches, so that no trace of the Glenwood beach remains.

Beginning about a mile northeast of Cudahy and extending northwestward through Bay View in a narrow strip between the small creek valley and the lake is a deposit of stratified clay, sand, and gravel, which, from its character, its elevation, and its general relations should probably be correlated with the Glenwood beach. The surface, however, has been so much modified by erosion and artificial excavation that no semblance of an actual beach now remains.

In this Bay View Bluff south of Rusk Avenue a bed of dense pebbly red clay, underlying sand and gravel, attains a maximum thickness of about 20 feet. As the bluff approaches the point northeast of Cudahy where it cuts into the east ridge of the Lake Border morainic system this bed of clay rises with the rise of the underlying till and disappears before the moraine is reached. The overlying sand continues to the probable position of the shore line at the border of the moraine. This pebbly red clay may be the continuation of the red clay deposit north of the harbor, or it may be a secondary deposit derived therefrom.

The stratified deposits underlying the pebbly red clay north of Milwaukee, which are regarded as having been deposited during the early part of the Glenwood stage of Lake Chicago, have already been described (pp. 310–313).

During the deposition of the stratified drift in Racine and Kenosha counties the glacial front is believed to have been so far melted away as to permit the influx of water from the Lake Superior basin across the Upper Peninsula of Michigan east of Marquette but not so far as to have opened an outlet eastward by way of the Straits of Mackinac. With the influx of this water came, it is believed, a large amount of fine red silt which was precipitated in the Glenwood waters. This probably continued until the readvancing ice, encroaching on the higher land, shut off the water from the upper lake basin. As the ice advanced, Lake Chicago, still standing at about the same level, was contracted. In Sheboygan County the glacier extended a maximum distance of about 14 miles inland from the position of the present shore line. The distance decreases southward to the southern part of Milwaukee, where the glacial front passed from the land into the lake basin. How much farther southward the lobe extended before the margin recurved to the east shore of the lake near Muskegon is not known.

As renewed melting of the ice contracted the margins of the lobe within the lake basin, Lake Chicago again extended its waters northward between the ice front and the gently rising slope of the land, until it found an outlet around the north end of the southern peninsula of Michigan to glacial Lake Algonquin in Huron Basin, and its waters escaped to the Hudson by way of Trent River, glacial Lake Iroquois in the Ontario Basin, and Mohawk River.

From Milwaukee northward nearly to the north line of Ozaukee County, a distance of 36 miles, the encroachment of the waters of later stages of the lake cut away all trace of the Glenwood shore line. But from northern Ozaukee County northward into southern Manitowoc County slight indications of submergence by Glenwood waters are found on the surface of red till in the low tract bordering the lake shore.

In northeastern Belgium Township (T. 12 N., R. 22 E.) indications of the Calumet beach are found and slight traces of gravels extend in places up the slope to the Glenwood level, but no definite beach exists. At the southeast corner of sec. 13, a mile east of Lake Church, 2 feet of gravel was found overlying red till; and a mile south, in a well on the slope at 640 feet above sea level, 10 feet of gravel was penetrated. Near the north line of sec. 14 (probably sec. 13) Goldthwait found a well-formed gravel ridge 60 feet above the lake. On the north, in the southern 5 miles of Holland Township, there is scarcely a trace of a shore line at the Glenwood level, though the low slope rising gently westward from the crest of the lower Nipissing bluff to this level is very uniform, except where cut by ravines, and resembles a lake terrace. Near the middle of sec. 5, 1½ miles east of Oostburgh, on a slight break in the slope, at an elevation of 63 feet as measured by Goldthwait, a gravel pit exposes cross-bedded gravels like those of a beach. West of this line the surface rises with slight undulations to the crest of the red-till ridge which is traversed by the Sauk trail road. Similar conditions continue northward through Sheboygan County to the vicinity of Cleveland in southern Manitowoc County. Nowhere is there a definite beach, but the flat terrace rises to a slight break in the slope at the Glenwood level with here and there slight traces of gravels, and west of this indefinite bank the surface becomes gently undulating. From Sheboygan northward this line is not far west of the railroad. In the NW. ¼ sec. 10, 2 miles north of Sevenmile Creek, a low ridge of cross-bedded fine beach gravels resembling a lake bar lies near the crest of the lake bluff at 640 feet above sea level. Though the phenomena in this lake border belt are scarcely definite enough to prove submergence in the waters of the Glenwood stage of the lake, they are just about what would be expected if such submergence lasted but for a comparatively short time while the ice in the lake basin melted sufficiently to open an outlet to the Huron basin.

North of Cleveland, just east of the railway, where Centerville Creek crosses the Glenwood shore line, an old delta deposit of gravels, spread over one-fourth to one-half square mile, declines radially from the point where the creek cuts the shore line. Later lowering of the lake and the extension of the creek eastward caused the cutting of a narrow valley through the deposit. Fisher Creek, which crosses the shore line about a mile farther north, shows no such delta. So also no delta was noted on Point Creek, 1½ miles still farther north. While the glacier stood at the moraine near Manitowoc it is probable that a broad stream, composed of glacial waters and of the drainage from the land area to the west, flowed southward from north of Fisher Creek along the west front of the ice with a current that may have been strong enough to sweep away the sediments brought to it by the creeks.

North of Centerville Creek the surface is in part a little higher and is gently undulating and shows no evidence of submergence. Near the lake shore it has the mild sag and swell topography of a marginal moraine and is, in part, lower than the lake plain to the south; but even here it does not appear to have been submerged. It is quite possible that while the ice front stood at this moraine the opening of an outlet to the Huron basin about the north end of the southern peninsula of Michigan occurred as a result of the melting of the ice and that the lake was then lowered from the Glenwood shore line.

STREAMS ASSOCIATED WITH THE GLENWOOD STAGE.

When the recession of the ice front first initiated Lake Chicago the glacial waters escaped southward by the Des Plaines River valley to the open lake in the south end of the basin between the Lake Border moraines. As the glacial front withdrew from the most easterly of these ridges in Milwaukee, Racine, and Kenosha counties, Wis., the upper part of Milwaukee River probably entered the lake somewhere in Ozaukee County, and Menominee River discharged its waters near the location of the present junction of the two streams at Milwaukee.

Kinnikinnic River entered the lake at Bay View and Oak Creek at some point east of the present lake shore. Root River, after cutting through the east ridge, flowed southward 4 miles and entered the lake near the Chicago & Northwestern Railway bridge in the western part of Racine. Pike River entered the lake 1½ miles west of Berryville, about 3½ miles above its present mouth.

When the glacier readvanced and deposited the red till Milwaukee River was turned southward and joined the Menominee at Milwaukee.

As the ice melted backward Onion, Mullet, and Sheboygan rivers flowed across the red-till plain. At first they discharged southward, but later they united near Sheboygan Falls and entered the lake near the site of the railway bridge in western Sheboygan Township. The meandering of these streams while held up by the lake level began the development of the broad valleys east of Sheboygan Falls. Pigeon River reached the lake near the stone quarry, and the other streams northward to and including Fisher Creek cut the shore line near the railway. The valleys of Fisher and Point creeks are terraced at levels corresponding to the Glenwood stage.

LOWERING OF THE LAKE LEVEL.

The long continuance of the water level at the Glenwood shore line indicates that, despite the large amount of water discharged, the outlet through the moraine near Chicago was lowered very slowly. The occurrence of shore phenomena from 60 to 65 feet above the lake down to 50 or 55 feet indicates that little lowering was going on. No rock sill in the outlet is known to have stood so high as the Glenwood level, although near Lemont, Ill., limestone is exposed 40 to 50 feet above the valley floor (620 to 630 feet above sea level). But as the moraine there is about 10 miles wide and is composed mostly of compact clayey till, its cutting to a depth of about 20 feet must have taken considerable time. A part of the lowering was accomplished during the Glenwood stage, but the larger part of it appears to have occurred rather suddenly. The only explanation of this relatively sudden drop thus far offered is that of Chamberlin,[1] who suggests that a slight fall may have been initiated by some inequality in the drift, such as a semi-indurated or bowldery mass, and may have worked headward after the manner of a cataract or a rapids until only a remnant of the barrier remained, and that this remnant was swept away with relative suddenness, somewhat as in the bursting of a dam, allowing the lake to be drawn down to a lower level. The shore line at this lower level marks the Calumet stage of Lake Chicago.

CALUMET STAGE.

The ancient beach marking the second stage of Lake Chicago was named by Leverett for Calumet River, with which it is closely associated in Illinois and Indiana. Its elevation near Chicago is about 35 feet above Lake Michigan, or 616 feet above sea level.

Goldthwait[2] has recently called attention to what are apparently remnants of a rock sill at Lockport, Ill., in the Chicago outlet, about 30 feet above Lake Michigan. Limestone is also exposed in the sides of the valley in the vicinity of Lemont up to 620 to 630 feet above sea level. A ridge may have extended across at this place with its crest a little lower than the top of the rock exposed in the valley sides and have constituted part of the barrier which maintained the lake at the Calumet level. This Calumet shore line is well developed all about the south end of the lake basin from Evanston, Ill., where it is cut off by the present lake shore, southwestward to the Chicago outlet and thence eastward through northwestern Indiana and northward into Michigan. A beach at a corresponding level has been traced by Leverett northward, with some interruption, to an outwash gravel plain bordering the main moraine of the Port Huron morainic system between Manistee and Ludington, Mich. Between Evanston and Wau-

[1] Chamberlin, T. C., Alternative interpretations, glacial Lake Agassiz: U. S. Geol. Survey Mon. 25, pp. 250-251, 1896.

[2] Goldthwait, J. W., Physical features of the Des Plaines Valley: Illinois Geol. Survey Bull. 2, pp. 54, 55, 1909.

kegan, Ill., the beach has been destroyed by the encroachment of the lake.

Goldthwait[1] describes this beach in the Waukegan, Ill., district, as follows:

> In the northern part of Waukegan, 2 miles north of the city (in sec. 9), scraps of terraces at altitudes appropriate to the Calumet stage appear on the face of the Toleston Bluff; but some of these at least seem to be old ravine terraces, preserved in a curiously exposed position.
>
> Near Beach station the Calumet ridge appears on the brink of the Toleston Bluff, and runs northward with short interruptions to the State line, never far from the bluff of the lower stage. Through Zion City it is followed by Elizabeth Avenue. Near Winthrop Harbor it was cut away during the Toleston stage for half a mile. Although usually a low, faint feature, and subdued by plowing, it is broad and strong between Zion City and the Camp Logan road.

From the State line to Pike River north of Kenosha the beach ridge lies one-half to three-fourths mile west of the lake. Beyond Pike River it follows the crest of the present lake bluff quite closely to a point north of Racine, where the present shore line diverges to the northwest and the ancient beach continues northward across Wind Point to 1½ miles northwest of the Wind Point lighthouse, where it is cut off by the lake. From this point northward for nearly 50 miles the subsequent encroachment of the lake has destroyed all trace of the beach.

The elevation at the State line as measured by Goldthwait is 35 feet above Lake Michigan, or 616 feet above sea level.

In the town of Belgium, between 5 and 7 miles north of Port Washington, a slight trace of a beach too poorly developed for certain correlation, appears on the slope at about the level of the Calumet shore line.

In Sheboygan County there is even less trace of the Calumet shore line, though it seems probable that the waters must have submerged the lower parts of the Glenwood plain. At a few places in the towns of Wilson and Holland slight ridges of sand and gravel occur at the Calumet level (about 620 feet above sea level), but north of Sheboygan little of the area is below this level. With the lowering of the lake the streams extended themselves across the plain below the upper shore line and eroded their channels.

A terrace remnant within the bend of Sheboygan River west of the Chicago & Northwestern Railway at Sheboygan and another on the opposite side of the river at the cemetery in the western part of the city are somewhat lower than the Glenwood plain to the north and south and probably represent the flood plain of the river at the Calumet stage. The elevation at the Schrier brewery (as measured by barometer) is about 614 feet above sea level.

Pike River crossed the lacustrine plain between the Glenwood and Calumet beaches and entered the lake 3 miles north of Kenosha.

Root River reached the lake at Racine very nearly at the same point as now but at a level about 40 feet higher. The meandering of the stream between Horlick's mill and the lake broadened the valley and developed the ancient flood plain represented by the upper alluvial terrace at Cedar Bend. This terrace is a flat-topped, table-like remnant, bounded on three sides by an abandoned valley and on the north by the present stream channel. It stands about 30 feet above Root River and is composed principally of till, overlain by 3 to 4 feet of alluvial gravels.

The lowering of the lake from the Calumet level to the Toleston beach was probably accomplished by cutting down the outlet—much as was the drop to the Calumet beach. After the cutting through of the rock sill at Lockport, Ill., noted by Goldthwait, the drift in the valley above would be more rapidly removed.

LOW-WATER STAGE.

Some time after the outlet had been so far cut down as to lower the lake to the Toleston level the recession of the ice front past the Straits of Mackinac opened a lower outlet eastward. There is abundant evidence that down to this time and somewhat later the land in this region and at the north end of Green Bay stood 100 or more feet below its present elevation. So also of the region of the Trent Valley, Ontario. It seems probable that the same condition prevailed when the melting of the ice first opened the Straits of Mackinac, and that the waters in the Michigan basin were drawn down below the level of the Chicago outlet by eastward discharge through the Trent Valley.

Following studies by Andrews[2] it was long supposed that a low-water stage intervened

[1] Goldthwait, J. W., op. cit., p. 63.

[2] Andrews, Edmund, The North American lakes considered as chronometers of postglacial time: Chicago Acad. Sci. Trans., vol. 2, art. 1, pp. 1-24, 1870.

between the Glenwood and Calumet stages. This belief was based on a deposit of buried peat, beneath sand which was found in the vicinity of Evanston, Ill., and was taken to indicate an emergence of sufficient duration to permit the accumulation of peat prior to the deposition of the beach sand and gravel of the Calumet stage. Later study is said by Goldthwait[1] to strongly suggest that the "peat" is merely a lacustrine deposit formed in quiet water behind a barrier during the Calumet stage and buried by shoreward advance of the bar.

There is, however, evidence that a low-water stage did occur, but it seems probable that it followed instead of preceded the Calumet stage. Borings along Milwaukee River for 1½ miles above its confluence with Menomonee River, on Clinton Street south of the confluence, and near the Kinnikinnic Avenue Bridge show marsh deposits, in some places below more or less sand, extending to depths of 20 to 53 feet below the level of Lake Michigan.[2] These facts indicate that at some stage the waters of the lake were drawn down to about 50 feet below their present elevation. This lowering of the lake level greatly increased the gradient of the lower Milwaukee and caused it to excavate its valley to the depths indicated. Subsequently the valley was partly refilled. As the filling is composed of marsh deposits, sand, and alluvium, and not of red clay, it is inferred that the lowering of the lake level occurred subsequently to the deposition of the red clay. Further than this, however, nothing has been observed indicating the time of its occurrence.

The fact that the level of the terrace of Root River at Cedar Bend in the southwestern part of Racine corresponds to the Calumet stage suggests that the low-water stage and accompanying trenching of the bottom of the valley followed the development of this terrace at the Calumet stage. It does not seem probable that if the valley had been cut deeper at a prior stage the stream would have meandered so as to develop this terrace when the lower part of the valley was drowned by a rise of the water to the Calumet level.

Sheboygan River has a broad flat-bottomed valley but the writer has been unable to determine whether or not this valley has been refilled. A well at the tannery on the flat three blocks south of the Chicago & Northwestern Railway station reached dolomite 55 to 65 feet from the surface, but the character of the overlying deposits is not known. Dolomite is exposed beneath the flood plain of Pigeon River near the bridge about three-fourths mile west of the lake shore, but there may have been some excavation and refilling between this and the lake shore.

Such a lowering of the water level would have exposed slopes formerly submerged by the lake waters. Deposits of vegetal material accumulated on these slopes, though likely to be subsequently destroyed, might be preserved in places if covered by deposits of a later partial submergence. This may perhaps explain certain deposits on the lake shore just north of Black River, 2½ miles south of Sheboygan Harbor. South of Lake View Park the bluff lowers to a low bank about 15 feet above the lake and strikes off to the southwest, away from the lake shore, as the landward margin of a low terrace, which (see p. 337) was probably formed at the Nipissing stage of the lake. Where the present shore cuts off this terrace there was exposed in 1908 the section illustrated in figure 21.

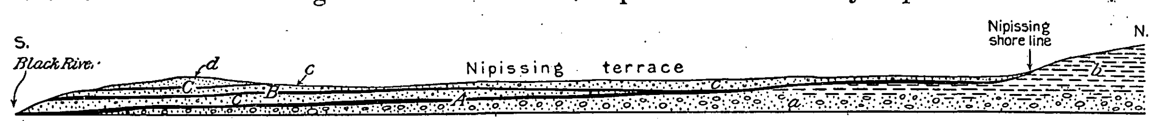


FIGURE 21.—Section exposed in lake bluff 2 to 3 miles south of Sheboygan, Wis.: *a*, Red till (Illinoian?); *b*, laminated red clay partly much contorted (Illinoian?); *c*, beach sand and gravel; *d*, dune sand; *A*, black vegetal layers, largely wood and peat; *B* and *C*, black humus layer, soil, and peat. Length of section, one-half mile; height, 25 feet.

The surface of the red till and contorted clay declines from the bank above noted nearly to the level of the lake at Black River mouth. In places the upper part of this clay is decolored to a grayish tint. When examined in 1908 there was upon this surface a bed of peat, twigs, and branches (*A*) in places 8 inches thick. Some of the largest branches were 3 inches or more in diameter. The whole was compacted into a mat of vegetal material and indicated a considerable growth on a low slope which was sub-

[1] Goldthwait, J. W., The physical geography of the Evanston-Waukegan region: Illinois Geol. Survey Bull. 7, p. 61, 1908.

[2] Alden, W. C., U. S. Geol. Survey Geol. Atlas, Milwaukee folio (No. 140), p. 6, 1906.

merged at the higher stages of the lake. This bed terminated near the landward margin of the terrace, and it is not known whether or not it originally extended higher up the slope. It may have done so and have been removed when the bank marking the Nipissing shore line was developed. This vegetal growth must have taken place at a low-water stage when the low slope emerged. Overlying the vegetal layer was 2 to 3 feet of sand and gravel. If a low-water stage occurred immediately after the Calumet stage the overlying sand and gravel probably represents the deposits of either the Toleston or the Algonquin submergence. This layer wedged out at the north end, possibly as the result of erosion when the waters again subsided. There was, overlying the sand and gravel, a layer of black peaty soil (*B*) 6 inches to 1½ feet thick. This seems to indicate a second interval of emergence, possibly following the Algonquin stage. This soil coalesced with the lower vegetal layer and then ended as the eroded bank was approached. Overlying the soil (*B*) was a second bed of sand which covered most of the terrace and extended up to the bank marking the Nipissing shore, about 14 feet above the present water level. A third humus layer (*C*), the recent soil developed since the emergence of this terrace, was partly covered by dune sand. In this section about one-half mile long and mostly less than 15 feet in height was the record of a notable series of events. When revisited in 1910 nearly all the vegetal material had been cut away by wave action and the record was destroyed.

A somewhat similar relation of deposits was found in the valley of the creek which enters the lake east of Newton station in southern Manitowoc County. Where the creek has cut near the road at August Stock's the following section was exposed:

Section of creek bank three-fourths mile east of Newton station, Wis.

	Feet.
Reddish sand	2–3
Stratified fine gravel, cross-bed dipping west	1–3
Black soil containing wood; lower part interstratified with sand	2
Dense, jointed, red till; upper 2 inches decolored, grayish; lower part in places laminated and contorted	5–7

A little farther east on Mr. Cerkwizcki's land the lower red clay is laminated and undisturbed. The valley is terraced and the sections exposing the bed of soil and wood beneath the stratified sand and gravel are below the terrace. Branches 1 to 6 inches in diameter occur in the vegetal layer, and at one point a log 1 to 2 feet in diameter extends clear across the ravine where the lower deposits have been cut away, and a second 2-foot log projects from the bank. The condition of the banks, however, at this place was such that it was not certainly determined that the logs may not have fallen more recently. Just north of Cerkwizcki's house the clay and vegetal layer disappear from the section, being replaced by stratified sand and gravel. The vegetal layer lies about 610 feet above sea level, per barometer, and it may have originated at the low stage following the Calumet stage of the lake. If such was the case the overlying sand and gravel represent the deposition which occurred when the Toleston waters backed up in the valley. Similarly, 2 miles farther south, in the NW. ¼ NE. ¼ sec. 11, Centerville Township (T. 17 N., R. 23 E.), about one-fourth mile southeast of F. Wadzinski's house, a bed of twigs and branches underlies the sand and gravel of a small terrace in Point Creek valley.

In discussing the Toleston beaches in the vicinity of Evanston, Goldthwait[1] says:

> A recent cross section in the bluff, where the ridge runs out to the lake, showed 1 foot of peat about 5 feet above the lake, beneath the Toleston gravels. Below the peat is a compact deposit of very fine gray sand of unknown depth. A single shell was found in the sand close to the peaty layer. A section studied by Leverett[2] in 1888 showed similar peat layers, with associated shell-bearing clays 9 feet above the lake. Dr. Oliver Marcy, in 1864, made a record of an exceptionally good exposure in the cliffs, which were than unprotected by the piers and artificial beach. The peat, a clay bed containing molluscan shells of nine genera (all existing specimens), was found 10 feet above the lake. Farther down, on the contorted glacial clays, was found a "humus soil, with stumps and logs (coniferous)" 6 inches thick and buried by 3 feet of gravel. A cellar excavation on Davis Street, Evanston, recently showed a peat bed between the blue bowlder clay and the overlying Toleston gravels and sands. Minute fibrous rootlets could be seen penetrating the till at the base of the peat, indicating that the deposit is in situ, presumably a land-surface deposit. If so, it registers a stage of low water preceding the Toleston.

It is reported that peat deposits were reached in sewer ditches in Hyde Park, Chicago, west

[1] Goldthwait, J. W., The physical geography of the Evanston-Waukegan region: Illinois Geol. Survey Bull. 7, pp. 65–66, 1908.

[2] Leverett states in a personal communication (1913) that he is now inclined to regard this beach as Algonquin. It seems to him to be the product of a lake full of molluscan life such as Lake Algonquin might have been but such as Lake Chicago is not as likely to have been.

of Grand Boulevard, beneath the deposits of the Toleston stage.

Correlative evidence of a low-water stage has also been found on the east side of the lake in Michigan. Leverett [1] finds that the soundings shown by the United States Survey charts from Pere Marquette Lake southward to the Kalamazoo River demand an emergence of at least 50 feet above the shore, even if the bottoms of the channels are but slightly filled, and it is regarded as not improbable that the amount of filling is such as to necessitate the assumption of an even greater emergence in that region. The same writer's observations in the vicinity of Holland, Mich., led to the view that the channeling occurred subsequent to the formation of a strong beach, which reaches 60 to 65 feet above Lake Michigan, and prior to the formation of a beach which stands 25 feet above the lake now regarded by Leverett as Algonquin.

Leverett [2] also describes the exposure of a deposit of peat in the lake bluff 12 to 15 feet above the present beach between Michigan City, Ind., and New Buffalo, Mich. At one place this is traceable for one-half mile. Near Michigan City it may be traced for a mile just above the water level. Above it is 30 feet of sand.

TOLESTON STAGE.

If these various phenomena really indicate the occurrence of a low-water stage of the lake, as they seem to do, and if the drop in the lake level occurred soon after the water had been lowered to the level of the Toleston beach by the cutting down of the Chicago outlet, it is probable that the refilling of the basin to this level was occasioned by a readvance of the ice that closed the Straits of Mackinac. It is also probable that the deposition of the red clay continued through the Calumet stage if not also through the low water and Toleston stages, and that the limit of the readvance is marked on the Wisconsin side of the basin by a red-till moraine, which extends southward to the lake shore just east of Two Rivers, and by a moraine, also partly composed of red clay, which Leverett has traced to the east shore of the lake in the region of Manistee, Mich. (See Pl. XXIII, p. 208.) In the Huron basin the ice is thought to have extended to the Port Huron morainic system and to have had approximately the same limits as at the next earlier advance. No trace of any of the three main shore lines of Lake Chicago is found on either the east slope of the moraine north of Two Rivers, Wis., or on the inner (lakeward) slope of the Manistee moraine in Michigan. Other beaches, however, are found, so that it is thought that when the ice front again receded from the moraines Lake Chicago was merged with Lake Algonquin. The shore line and beach formed at the last stage of Lake Chicago were designated Toleston by Leverett from the village of Toleston in northwestern Indiana, which was built thereon. This village is now merged in the city of Gary, Ind.

At Evanston, Ill., near Calvary, Goldthwait [3] found that the top of the gravels exposed in a section of the beach was 22 feet above Lake Michigan, or 603 feet above sea level. Ridges on the campus of Northwestern University he found to stand 24, 23, 19, 16, and 14 feet above the lake, with some others between 10 and 15 feet.

In the vicinity of Chicago and leading into the Chicago outlet what has been regarded as the main Toleston shore line lies about 20 feet above Lake Michigan, or 600 feet above the sea, although in places the gravels are piled in ridges somewhat above this level and in others a terrace at the foot of a low but well-marked cliff is somewhat below it. There are also numerous ridges of sand and gravel as at Evanston, the whole showing the effects of a gradually lowering lake level. The bottom of the outlet at Summit, Ill., is 15 feet above the level of Lake Michigan.

No deposits observed in eastern Wisconsin clearly indicate the stand of the waters of Lake Chicago at the Toleston level. If such were formed they were removed by erosion at a following slightly lower stage—the Nipissing stage. The sand and gravel above the vegetal layer shown in figure 21 (p. 333) is thought by Leverett to represent the Algonquin stage.

GLACIAL LAKE ALGONQUIN.

When the ice front had retreated so far as to permit the confluence of the waters of the

[1] Leverett, Frank, The Illinois glacial lobe: U. S. Geol. Survey Mon. 38, pp. 440-443, 446, 1899.

[2] Leverett, Frank, and Taylor, F. B., The Pleistocene deposits of Indiana and Michigan: U. S. Geol. Survey Mon. 53, p. 356, 1915.

[3] Goldthwait, J. W., op. cit., p. 66.

Superior, Michigan, and Huron basins these are believed to have discharged at first eastward via an outlet at Kirkfield, Ontario, and thence across the Ontario basin, then occupied by glacial Lake Iroquois, to the Mohawk Valley and the Hudson. A little later the Kirkfield outlet was closed by uplift of the land and the outflow escaped partly by the Chicago outlet and partly past Port Huron to Lake Erie and thence to Lake Iroquois and the Mohawk.

Eventually the ice melted from the Superior basin so that its waters became confluent with those of the Huron and Michigan basins. (See Pl. XXXVII.) Spencer [1] gave the name "Algonquin" to the main beach as found in the Huron basin, but he regarded it as having been formed by marine waters during a depressed condition of the continent. The name has been retained, though the interpretation now generally held is that the waters were fresh and were maintained at the level of this shore line by the closing of lower outlets by the glacial ice dam. The water body has therefore come to have the name Lake Algonquin.

It is believed by those who have given the subject most careful study that the main uplift of the region to the northeast occurred during this stage. This is indicated by the northward rise and the splitting and divergence of the beaches. Goldthwait made a study of the abandoned shore lines in the Lake Michigan basin with careful measurements and correlation of the several strands. The results of these studies are embodied in the papers cited above (p. 326). He states [2] that "recent studies have strengthened the belief that the 15-foot member of the Toleston group of beaches does not mark the shore of a local Lake Chicago but of two of its larger successors, Lake Algonquin and the Nipissing Great Lakes."

Leverett thinks the Algonquin waters reached levels 20 to 25 feet above Lake Michigan or to the highest of the Toleston beaches.

Deepening of the Port Huron outlet gradually reduced the flow from the Chicago outlet, and continued recession of the ice front finally removed the barrier from the Ottawa Valley and permitted discharge by this outlet. (See Pl. XXXVII.) This is believed [3] to have drawn down the waters in the Michigan basin to a level below that of the present beach in the southern half of the basin.

The only phenomenon observed along the Wisconsin shore which may be regarded as evidence of a lowering of the lake water at this stage is the intermediate soil (*B*, fig. 21, p. 333) buried beneath the sand and gravel of the Nipissing terrace near the mouth of Black River, south of Sheboygan. This seems to indicate a second emergence of the low slope bordering the lake shore. Perhaps with this should be correlated the bed of peat underlying beach gravel which was observed south of Kenosha. About one-fourth mile south of the mouth of the creek which enters the lake a mile south of Kenosha Harbor, there was exposed in July, 1899, 1 foot of peat overlying solid bluish till and underlying beach sand and gravel which is piled 13 to 15 feet above the water level. The upper part of the ridge is of dune sand. These deposits indicate an interval of emergence followed by submergence, probably in the waters of the Nipissing stage, whose well-marked shore line lies about one-fourth mile farther west, at the cemetery. This stage may be regarded as closing the Pleistocene history of the area under discussion, for it ended the direct influence of the glaciers on the phenomena of this district.

POSTGLACIAL LAKE DEPOSITS AND HISTORY.

NIPISSING GREAT LAKES.

The discharge eastward from North Bay, Ontario, and thence through the pass between Lake Nipissing and Ottawa River, was finally closed by the northward elevation of the land resulting in the southward tilting of the lake basins. In consequence of this the flow through the outlet at Port Huron was resumed. The three upper lakes at this stage are known as the Nipissing Great Lakes [4] (Pl. XXXVIII) and the shore line marking this stage as the Nipissing shore line or Nipissing beach. Concerning these shore lines in Illinois Goldthwait says: [5]

> The shore lines of the Nipissing stage are characterized by an exceptionally strong development of cut bluffs and

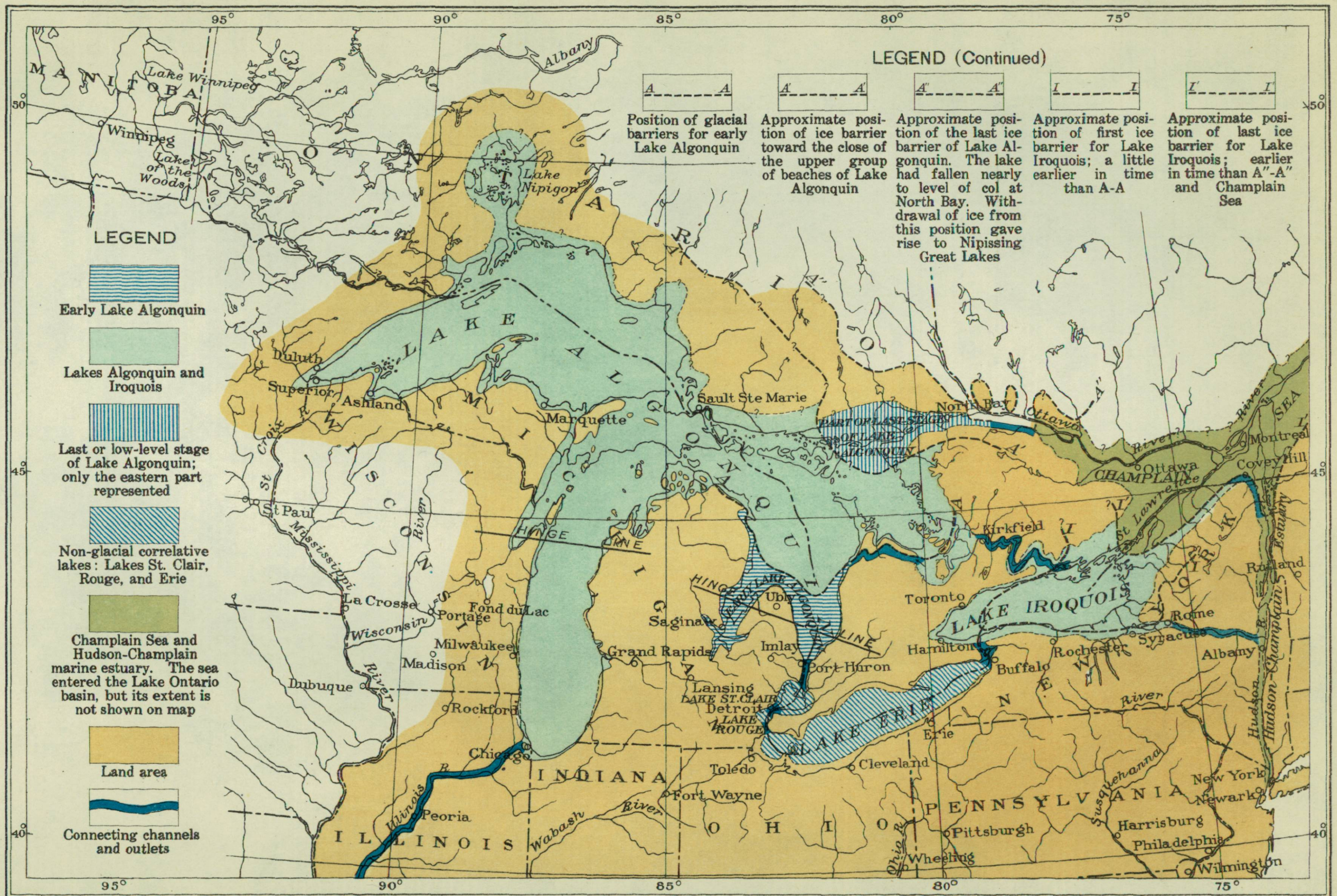
[1] Spencer, J. W., Notes on the origin and history of the Great Lakes of North America: Am. Assoc. Adv. Sci. Proc., vol. 37, pp. 197-199, 1889.

[2] Goldthwait, J. W., Physical geography of the Evanston-Waukegan region: Illinois Geol. Survey Bull. 7, p. 64, 1908.

[3] Idem, p. 66.

[4] Taylor, F. B., Preliminary notes on the studies of the Great Lakes made in 1895: Am. Geologist, vol. 17, pp. 253-257, 1896.

[5] Goldthwait, J. W., Physical geography of the Evanston-Waukegan region: Illinois Geol. Survey Bull. 7, p. 66, 1908.



MAP OF GLACIAL LAKE ALGONQUIN AND ITS CORRELATIVES

By Frank B. Taylor and Frank Leverett

100 0 100 200 300 Miles

House Doc. No. ; 64th Cong., 2d Sess.

1917

terraces, rather than by beach ridges. In this manner they express the vigorous encroachment of a lake which was rising upon its shores.

It is largely on the basis of the relatively strong development of the shore features that correlation of one of the old strands of southeastern Wisconsin with the Nipissing shore line is made.

Between 4 and 5 miles south of the north boundary of the area under discussion a remnant of a well-developed wave-cut terrace extends from a mile north of Centerville southward to the mouth of Centerville Creek. (See Pl. III, in pocket.) This terrace stands about 12 feet above the present lake shore, has a maximum width of about 30 rods, and is bordered on the west by an abrupt 30-foot cliff of drift. Near its lakeward margin it carries sand dunes.

Thence southward 14 miles along the lake shore to a point about 2 miles south of Sheboygan Harbor, no trace of this Nipissing terrace remains, although the valleys of all the streams entering the lake south of Manitowoc are terraced at a corresponding level, as in the broad flat bottoms bordering Pigeon and Sheboygan rivers in their lower courses. From a point about one-half mile north of the mouth of Black River, in Wilson Township (T. 14 N., R. 23 E.), southward through Holland and Belgium townships, to 5 miles northeast of Port Washington, a terrace at the Nipissing level is bordered on the west by a bank or low cliff. Black River cuts this ancient shore line near the south line of Wilson Township and flows thence northeastward nearly 6 miles through a marshy belt behind an accumulation of dune sand which has been blown up onto the terrace from the present beach. In Holland and Belgium townships the low bank rises, becoming a turf-covered cliff 20 to 30 feet in height. Goldthwait's measurements show that this shore line, which is believed to mark the Nipissing stage, is about 14 feet above Lake Michigan.

If the middle deposit of vegetal material exposed in the low bluff beneath this terrace just north of the mouth of Black River (see p. 334 and *B*, fig. 21) was formed during the emergence of the slope at the low-water stage preceding the Nipissing stage the overlying bed of sand and gravel, which extends up to the 14-foot level, represents the deposits of the Nipissing stage.

In sec. 19, T. 12 N., R. 23 E. (Belgium Township), Devonian limestone rises slightly above the present lake level and is exposed on the beach and at the quarry of the Northwestern Lime Co. The presence of this ledge has protected the ancient terrace from the attacks of the waves. Southward for 1¾ miles the terrace is very narrow. In sec. 36, T. 12 N., R. 22 E., the presence of another ledge affords protection, and 1 mile farther south in sec. 1, Port Washington Township, another outcropping of the limestone has preserved a scrap of the terrace 100 yards wide.

From this latter point southward for 17 to 18 miles, to within one-half mile of the north line of Milwaukee County, vigorous erosion by the waters of Lake Michigan has removed all trace of the Nipissing shore line. For nearly a mile north of Fox Point the foot of the bluff is bordered by a terrace having a maximum width of about 75 yards. For a short distance at the tip of Fox Point the terrace has been removed by wave action, but beyond this for 1¾ miles it has an especially fine development. (See Pl. XXXIX.) In the Milwaukee folio [1] this terrace was figured as formed at the Toleston stage of Lake Chicago. On page 9 of the text, however, reference was made to Goldthwait's conclusion that it probably represented shore phenomena of the Nipissing Great Lakes. This correlation is accepted by the present writer as the more probable. The terrace is nearly flat, has a width of 10 to 40 rods, and rises gradually from a few feet above the present beach to the foot of the bluff, where it is about 15 feet above the present lake level. From this terrace a partly wooded bluff rises 80 to 100 feet to the undulating surface of the red-till upland.

Opposite the mouths of ravines which cut the bluff at intervals small alluvial fans, largely of red clay, have been washed down from above and spread out over the lake sand and gravel on the terraces. With the lowering of the lake level the streams cut through the fans and extended their channels across the terrace to the lake shore.

[1] U. S. Geol. Survey Geol. Atlas, Milwaukee folio (No. 140), pp. 5, 9, fig. 11, 1906.

Nowhere else in Milwaukee County is there a trace of the Nipissing beach. Very likely it is represented by parts of the alluvial deposits in the Menominee Valley west of the stockyards at Milwaukee and in the Root River valley in the western part of Racine, but the shore line itself does not reappear north of Kenosha. In the southern part of this city on the east side of Park Avenue a well-defined beach extends southward. A similar but slightly higher bank in the west part of the park may represent the Toleston shore. South of the creek these coalesce in a strong ridge of sand and gravel capped with dune sand 10 to 15 feet in height. For some distance this is traversed by the Chicago & Northwestern Railway. This beach is bordered on the east by a narrow marshy strip between which and the lake is another ridge of sand and gravel capped with dune sand. When visited by the writer in 1899 there were exposed at the north end of this ridge, about one-fourth mile south of a creek, a bed of peat 1 foot thick lying upon the solid blue till and overlain by beach sand and gravel capped with dune sand. This seems to indicate a low-water stage or an interval of emergence preceding the deposition (probably at the Nipissing stage) of the beach gravel. Two and one-half miles farther south this ridge shifts westward and coalesces with the main ridge. As the latter is traced southward the relief on the west decreases and that on the east increases and the ridge gives place to a cliff, whose front the railway gradually descends. At the State line the junction of the terrace and the base of the cliff was determined by Goldthwait to be 13 feet above Lake Michigan. This cliff continues a notable feature southward just west of the railway until intersected by the present shore line in the southern part of Waukegan, Ill.

Elevation of the région to the northeast continued during the Algonquin and Nipissing stages, but Goldthwait's careful measurements of the altitude of the beaches on both the west and east sides of Lake Michigan indicate that very little, if any, change took place in the southern half of the Michigan basin. Not until north of latitude 44° N., the north limit of the area under discussion, do the old shore lines in eastern Wisconsin begin to rise above the horizontal. The tilting for some distance is very slight, but the rate gradually increases as the result of the differential uplift, so that the Nipissing shore line, which in the area under discussion is 13 to 15 feet above Lake Michigan, is, at the north end of the basin, nearly 50 feet higher than the present beach (the Algonquin shore line is about 200 feet higher). This rise of the land has shallowed the lake very notably in the northeastern part of the basin.

Knowledge of the relations of the ancient shore lines in the northern half of the Michigan basin is due principally to the studies of Taylor, Leverett, and Goldthwait, although numerous other observers have contributed thereto.

LAKE MICHIGAN.

The adjustment of the depth and capacity of the outlet at Port Huron to the discharge from the upper lakes gradually lowered the water level in the Huron and Michigan basins to their present altitude and initiated the present stage of the lakes. To this stage of the waters in the western basin the name "Lake Michigan" is applied. The present level of the lake is approximately 581 feet above sea level. Along the west shore of Lake Michigan in Illinois and Wisconsin the shore work has been confined almost entirely to erosion and transportation, and permanent deposition has taken place at very few points and in small amounts. It is this work of erosion that has cut back the lake bluff to its present position, so far obliterating the records of former lake stages. This work of cutting back the bluff is going on constantly at various points along the shore.

The rate of encroachment of the lake upon the land depends very largely on the character of the material forming the shore. Where much sand and soft clay occur in the bluff, as in Milwaukee Bay and in the bluff near Racine, erosion is easy and the bluff recedes rapidly. In the towns of Mequon and Grafton, Ozaukee County, there has been much slumping down of the bluff in places. Where dense stony till occurs, particularly at the base of the bluff, erosion is much slower and salients are formed, as at Fox Point and North Point north of Milwaukee and south of Milwaukee Bay. Where the rock outcrops at the water's edge, as at the lighthouse point north of Sheboygan and at Wind Point north of Racine, recession of the shore line has practically ceased and prominent points have resulted.

Since the settlement of the lake-shore region this encroachment of the lake upon the land

ENGRAVED AND PRINTED BY THE U.S. GEOLOGICAL SURVEY

MAP OF NIPISSING GREAT LAKES AND CORRELATIVES

By Frank B. Taylor and Frank Leverett

100 0 100 200 300 Miles

1917

House Doc. No. ; 64th Cong., 2d Sess.

has been a serious menace to property, and in late years it has become necessary to build piers and breakwaters at frequent intervals to protect the shore from erosion. This artificial interference has greatly reduced the effective work of the waves.

In 1870 Andrews published [1] the following results of a series of observations on the rate of erosion along the west shore of Lake Michigan:

To determine the rate of erosion on the west coast of Lake Michigan I have through several years accumulated a large number of observations, mostly derived from surveys. In obtaining them I have used the utmost care to reject all loose, vague estimates having no tangible basis as well as all erosions brought to my notice because of their remarkable rapidity. I am confident that the subjoined figures present a fair average of the recession of the shore between Manitowoc and Evanston (near Chicago), which is the same stretch of 180 miles of coast whose terrace of erosion we have already examined. The period of observation in the following cases varies from 10 to 35 years:

	Feet a year.
At Evanston the erosion is	16.95
At the Old Pier, 2 miles farther north	4.90
One mile farther north	3.08
At Winnetka	4.05
One mile farther north	6.05
Lake Forest	1.65
Waukegan	.00
Two miles farther north	.00
State line	16.50
Kenosha	12.00
Two miles farther north	3.00
Three miles farther north	12.00
Racine Point	16.00
Racine	6.00
Oak Creek	2.00
One mile farther north	1.60
Milwaukee	6.25
Port Washington	2.30
One mile farther north	1.50
Place farther north	3.00
Place 4 miles south of Sheboygan	8.00
Sheboygan	6.25
Manitowoc	5.00

Milwaukee stands very near the center of this coast line, dividing it into halves. The north half, as the above figures show, is eroded less rapidly, and the terrace of erosion is therefore narrower than in the south half. From Milwaukee to Manitowoc (about 80 miles) the erosion averages 4.33 feet a year, while between Milwaukee and Evanston it is 6.24 feet a year. The average of the two is 5.28 feet, which is therefore the average erosion of the bluffs along the whole line. This result is confirmed by numerous other observations which were of value but not precise enough to be entered in the list.

[1] Andrews, Edmund, The North American lakes considered as chronometers of postglacial time: Chicago Acad. Sci. Trans., vol. 2, art. 1, pp. 7-8, 1870.

Chamberlin [2] publishes the results of a series of careful measurements made by S. G. Knight to determine the rate of encroachment in Racine County:

Mr. S. G. Knight, of Racine, has carefully measured for the Geological Survey, from the nearest section corner or quarter post to the bank of Lake Michigan, along all the section lines in Racine County, the results of which, compared with the Government survey made in 1836, are given in the following table. Had these measurements been made at right angles to the shore line, the result would have been a trifle less; but as some portions of the bank have been protected artificially we may assume the result as a close approximation to the actual amount of loss during the past 38 years in Racine County. These measurements will have their value many years hence.

Erosion of the lake shore in Racine County, Wis.

Section lines.	1836	1874	Loss.
	Chains.	*Chains.*	*Chains.*
North line of sec. 6, T. 4, R. 23	32.70	30.30	2.40
North line of sec. 7, T. 4, R. 23	34.68	33.45	1.23
West line of sec. 8, T. 4, R. 23	30.18	29.70	.48
North line of sec. 17, T. 4, R. 23	16.38	14.60	1.78
West line of sec. 16, T. 4, R. 23	10.86	9.75	1.11
North line of sec. 21, T. 4, R. 23	15.58	14.50	1.08
West line of sec. 22, T. 4, R. 23	19.39	18.43	.96
North line of sec. 27, T. 4, R. 23	26.39	26.39	.00
North line of sec. 34, T. 4, R. 23	16.04	15.47	.57
West line of sec. 34, T. 4, R. 23	31.50	30.00	1.50
South line of sec. 33, T. 4, R. 23	28.87	27.34	1.53
North line of sec. 4, T. 3, R. 23	28.03	26.50	
North line of sec. 9, T. 3, R. 23	18.82	18.00	.82
North line of sec. 16, T. 3, R. 23	27.80	20.60	6.20
North line of sec. 21, T. 3, R. 23	21.25	18.00	3.25
North line of sec. 28, T. 3, R. 23	32.22	31.16	1.06
West line of sec. 28, T. 3, R. 23	30.20	23.87	6.33
North line of sec. 32, T. 3, R. 23	34.85	32.40	2.45
South line of sec. 32, T. 3, R. 23	46.60	44.73	1.87
Mean of 18 places, in chains			1.92
The same, in feet			126.72
Loss per annum in feet			3.33

The following measurements were made to ascertain the amount of the abrasion of the west shore of Lake Michigan in Milwaukee County since the Government survey made in 1835 and 1836:

Section lines.	1835	1874	Annual loss.
	Chains.	*Chains.*	*Feet.*
South line of sec. 1, T. 5, R. 22	45.61	44.50	1.90
South line of sec. 36, T. 6, R. 22	15.90	14.40	2.60
South line of sec. 24, T. 6, R. 22	19.29	18.70	1.00
South line of sec. 21, T. 7, R. 22	8.72	8.42	.50
South line of sec. 15, T. 7, R. 22	5.37	2.82	4.31
South line of sec. 10, T. 7, R. 22	43.35	41.64	2.90
South line of sec. 3, T. 7, R. 22	19.34	17.36	3.33
South line of sec. 34, T. 8, R. 22	22.00	18.69	5.61
Mean annual loss			2.77

The material obtained by this erosive work of the waves is assorted, redistributed, and redeposited. The finer clay is borne backward into the lake and deposited in the deeper waters offshore. After a storm the water for a considerable distance from shore is decidedly

[2] Chamberlin, T. C., Geology of Wisconsin, vol. 2, pp. 231, 232, 1877.

roilly. The coarsest material (gravel, cobblestones, and bowlders), is left along the beach at the foot of the bluff. The sand which accumulates along the shore is continually being shifted from place to place by the waves. Along the west shore of the lake the prevailing movement, which is southward, has caused great accumulations of beach and dune sand at the head of the lake, and continually lodges sand on the north side of every pier and breakwater, and obstructs streams and harbors by forming bars across their mouths. This was well illustrated by conditions at the mouth of Milwaukee River prior to the cutting of the present harbor inlet through the bar.[1]

Sand blown from the present beach has piled up between Black River and the lake shore a belt of dunes that extends from Wilson Township, Sheboygan County, southward into Holland Township. Similar accumulations of dune sand are found on the ridge extending southward from the cemetery south of Kenosha and also between this ridge and the lake shore.

One curious effect of wave cutting at the foot of the bluff is seen north of Kenosha, where for three-fourths mile the ridge separating the Pike River valley from the lake has been cut away and the stream diverted to the lake at a point $1\frac{3}{4}$ miles north of its previous mouth at Kenosha Harbor. The lower half mile of the abandoned valley is the sag leading northward from the harbor to the lake shore. This phenomenon was described in 1847 by I. A. Lapham.[2] Attention was also called to it by Chamberlin[3] and later by Goldthwait,[4] who calls the process "intercision" and describes it as "a peculiar sort of modification of drainage which is slightly allied to river piracy, but in which the diversion is accomplished by the cutting back of bluffs along a lake shore."[5]

RECENT PHENOMENA.

WORK OF STREAMS.

The withdrawal of the glaciers from southeastern Wisconsin initiated the present régime throughout the area. Owing to the comparative recency of the disappearance of the glaciers, the work accomplished by the streams is very slight. Large parts of the area are practically untouched by erosion, so that lakes and marshes are numerous. Streams initiated by glacial waters dwindled, after the discontinuance of this discharge, to the meager proportions demanded by their small drainage basins. (See also pp. 33–38.)

Even so large a stream as Wisconsin River has accomplished relatively little erosion during the present cycle, its principal work being the cutting of The Dells gorge in the Cambrian sandstone and the cutting of the terminal moraine deposits both north and south of the Baraboo Bluffs. Elsewhere within the area under discussion its postglacial channel is shallow and trenchlike.

Rock River and the tributary Crawfish River meander through marshes and among drumlins in similar shallow channels. Owing to the relatively short time since its establishment in its post-Wisconsin course and to the retardation offered by the rock sills below Lake Koshkonong, Rock River and its tributaries have accomplished little in the way of draining the extensive wet lands within the terminal moraines. The cut through the outer moraine, which has a maximum depth of about 150 feet, and the channel in the outwash gravels beyond are mostly very narrow. Similar conditions characterize all the other streams of the area. Nowhere has a mature topography been developed by the streams during their present cycle.

VEGETATION AND SOILS.

As the climate became warmer after the disappearance of the glaciers, atmospheric, chemical, and organic forces attacked the superficial part of the drift and developed a soil. Vegetation gained a foothold and contributed to the formation of the rich humus layer which generally characterizes the soil of the area. The abundant depressions in the surface of the drift in which water accumulated fostered the growth of marsh and swamp vegetation and in places led to the formation of considerable deposits of peat.

No investigation of the thickness and character of these peat deposits has been made by the writer. It is probable, however, that the total amount which may become available for

[1] U. S. Geol. Survey Geol. Atlas, Milwaukee folio (No. 140), pp. 9, 10, 1906.

[2] Lapham, I. A., On the existence of certain lacustrine deposits in the vicinity of the Great Lakes usually confounded with the "Drift": Am. Jour. Sci., 2d ser., vol. 3, pp. 91, 92, 1847.

[3] Geology of Wisconsin, vol. 2, p. 130, 1877.

[4] Goldthwait, J. W., The abandoned shore lines of eastern Wisconsin: Wisconsin Geol. and Nat. Hist. Survey Bull. 17, pp. 48–50, 1907.

[5] Goldthwait, J. W., Intercision, a peculiar kind of modification of drainage: School Sci. and Math., vol. 8, No. 2, pp. 129–139, 1908.

WAVE-CUT TERRACE SOUTH OF FOX POINT, WIS., PROBABLY FORMED AT THE NIPISSING STAGE OF THE GREAT LAKES.

Ancient cliff of till at left. Fox Point in the distance.

fuel is very considerable.[1] It is also probable that considerable deposits of marl may be found in some of the lake and swamp areas. (See also pp. 44 and 47.)

East of Sugar River, in the towns of Newark and Avon, Rock County, and the towns of Shirland and Rockton, Winnebago County, Ill., is a considerable deposit of sand which is in part heaped into low dunes. Sandy loam also extends south onto the upland south of the Pecatonica in Illinois. This sandy deposit appears to be confined to the area east of Sugar and Pecatonica rivers, suggesting that it is a wind deposit blown from the broad alluvial flats bordering these streams and is derived, in large part, from the finer material of the outwash which was swept down the Sugar River valley from the front of the Wisconsin ice sheet.

BROWN LOAM AND LOESS.

Distribution and character.—The deposits of loamy clay, sandy loam, and loess that mantle the surface of the Illinoian drift have already been described. (See pp. 174–176.) Similar deposits mantle much of the surface of the drift of the Green Bay Glacier, showing that deposition of such material has occurred since the disappearance of the ice of the Wisconsin stage.

Sandy soil and sandy loam are found principally in the part of the area underlain by the sandy drift and the Cambrian sandstone—that is, in the lower tracts bordering Wisconsin and Fox rivers north and west of the irregular escarpment formed by the margin of the Lower Magnesian limestone. Here and there it overlaps the marginal parts of the limestone belt. In places the sand is blown into low swells and ridge dunes and is more distinct from the underlying sandy drift than elsewhere. It is derived from the sandy drift and the sand bars along Wisconsin and Fox rivers.

Southeast of the sandy belt, throughout the area underlain by the Trenton limestone and Galena dolomite, the deposit is principally a brownish noncalcareous clay loam. It differs from the underlying drift in texture, being finer and more even grained and generally lacking pebbles. Some bowlders which lay on the surface of the drift are seen buried in the superficial clay mantle. This brown loam grades eastward in Dodge and Jefferson counties into a grayish stoneless clay somewhat more compact than the brown loam and resembling dust derived from the grayish till. This extends eastward up over the Niagara escarpment and is more or less generally present in the area traversed by the Lake Michigan Glacier. The mantle of the brown loam and grayish clay gives to the area generally a soil containing comparatively few stones, even where the underlying drift is full of pebbles and bowlders. Where such a mantle is not present, as in considerable parts of the morainal belts, the soil is much more stony.

Where the brown loam attains a thickness of about 5 feet it has the characteristics of, or grades into, typical loess. The writer is of the opinion that the clay loam and the loess are one and the same and are principally of eolian origin. Where the loam is so thin that the effects of weathering have extended clear through it and into the underlying till the carbonates are entirely removed, the other minerals are partly decomposed, and the color and texture are so changed that the characteristics of unaltered loess are destroyed. Where the deposit is 5 to 6 feet or more in thickness the effects of weathering are largely confined to the upper part and the porous texture and columnar structure of the typical loess remain, and in many places enough of the carbonates remain to appear as efflorescence and concretionary "kindchen."

Overlying the slopes and uplands, generally outside the terminal moraine of the Wisconsin stage in the Baraboo region and farther west, is a brownish clay loam. This has been observed more particularly in the Baraboo, Denzer, and Dells quadrangles, where it occurs indiscriminately on the quartzite range, on the limestone-capped ridges, and on the sandstone, presenting everywhere much the same characteristics, except that in some places it is more sandy on the sandstones. Not infrequently thicknesses of 3 to 5 feet are seen, but generally there is less. The clay is loose and more loamy when dry than the sticky reddish residual clay which in many places immediately overlies the limestone and in some places the quartzites in the Driftless Area. When wet it is very sticky. It is generally buff to brownish in color and noncalcareous. Under the microscope it is seen to be composed of very fine angular particles of minerals, principally quartz. It

[1] Huels, F. W., The peat resources of Wisconsin: Wisconsin Geol. Survey and Nat. Hist. Survey Bull. 45, 1915.

is finer than the typical loess but not so fine nor even grained as the glacio-lacustrine clays. (See table, p. 176.) In one or two places in the Dell Creek valley this clay extends down from the slopes and onto the lowland submerged by the waters of glacial Lake Wisconsin, but in most places it gives place to loose sand. In the wooded tracts its extent has not been determined, but its distribution is so general that it is probably practically continuous on the slopes and ridges. Outside the Wisconsin terminal moraine and above the level of the submergence by waters of the Wisconsin stage it may be of pre-Wisconsin age. (See pp. 174–176.)

As stated above, in places this brown loam is associated with or grades into typical loess. Several occurrences of loess in connection with Wisconsin drift have been described by Salisbury,[1] who says:

Devils Lake.—East of the south end of Devils Lake fresh railway cuts reveal the presence of loess on the terminal moraine of the Wisconsin epoch. The crest of the moraine along the line of the railway at this point is, according to the topographic map, between 60 and 80 feet above the lake. The loess may be seen on both the inner and outer slopes of the moraine but does not cover its summit, failing to reach it on either side by about 10 feet.

While some of the loess here is thoroughly typical, it locally grades, either horizontally or vertically, into clay which is very unlike loess. It is sometimes capped by several feet of heavy clay, which is clearly not the product of loam weathering. Calcareous concretions occur but rarely, as also those of iron oxide. Shells were not seen. The loess, and especially the associated and genetically equivalent clay, contains an occasional stone of considerable size. The loess and the clay which goes with it have a maximum thickness of not less than 15 feet.

There seems to be adequate reason for believing that the loess on the outside of the moraine (toward the lake) was accumulated in the expanded lake which occupied the site of the present lake and its surroundings at the time of ice occupancy. There is independent evidence that the lake stood at least 65 feet above its present level. This evidence is found in the presence of what appear to be berg-floated bowlders up to this height about the borders of the depression (then a bay) at the southwest corner of the lake.

The loess on the inner slope of the moraine doubtless settled out of water which stood there after the ice had withdrawn a short distance to the east.

Ablemans.—Ablemans is about 8 miles west of the moraine of the Wisconsin epoch and in an area not overspread by the ice of an earlier epoch. Here at the extensive sandstone quarries there is a fine exposure of loess not less than 20 feet in thickness. It occurs at a rather low altitude and in such topographic relations as to bring it into unmistakable connection with the broad lacustrine (now terrace) flat which occupies the valley of the Baraboo from Baraboo to Ablemans. The exposure is in a ravine tributary to the Baraboo and but a few rods from it. The lacustrine flat with which this loess is to be correlated is generally made up, superficially at least, of laminated calcareous clay, very unlike loess. It is to be especially noted that the loess at Ablemans does not occur next the moraine but 8 miles away in a small tributary ravine, the head of which does not receive glacial drainage, and that much finer deposits (clay) occur in the main valley between the loess and the moraine where the water was discharged from the ice to the lake. The loess is here rich in calcareous concretions and in gastropod shells of the types which abound in the loess. It also possesses the normal loess texture and structure. Indeed much of it is not wanting in a single distinctive loess characteristic. Bones of small mammals, as yet unidentified, were found at this point, at least 10 feet below the top of the loess, and in such relations as to make it certain that the loess had not been disturbed nor the bones introduced since the deposition of the formation. The loess here lies against a steep slope of sandstone and quartzite and occasionally contains fragments of each.

A few rods away, at the same or approximately the same level, an exposure in an isolated remnant of the terrace shows it to be made up of sand interbedded with loam which approaches loess in texture. The sand and loam are distinctly stratified and the stratification appears to be the work of water. The sand and loam at this exposure do not lie against a rock slope and no stones or pebbles were found in it.

The occurrence of loess at Ablemans is of special interest, because it connects itself with the deposits of the lake which formerly occupied the valley of the Baraboo above the city of the same name. The lake was called into existence because the ice blocked the eastward drainage of the valley. It was maintained for a short time after the ice retired by the moraine dam, which is left just above the city of Baraboo. Its position in a ravine through which glacial drainage did not flow is also of significance.

The loess at Devils Lake and at Ablemans, like that in the vicinity of Green Lake, was certainly deposited by water and by water associated with the ice of the last glacial epoch. With the loess of Ablemans is to be correlated the clay in the valley of the Baraboo exposed at various points above the city, and the loams and clays, some of which are very loesslike, in the valleys of Seeleys and Narrows creeks west of the Baraboo. The loam at Logansville in one of these valleys was seen many years ago to contain shells and to be in other ways somewhat loesslike. At this point (Logansville) it is distinctly stratified, in places at least, and constitutes, or at any rate covers, the valley flat.

Baraboo.—In addition to the distinct development of loess at Devils Lake the surface of the drift about Baraboo is often marked by loam no less distinct than that about Green Lake. The surface loam does not seem to be restricted to the surface of the drift but affects the extraglacial surface as well. Even the high quartzite ridges seem to have a capping of it, though it can not be affirmed that the loam (or clay) on these ridges is the equivalent of that over the drift.

[1] Salisbury, R. D., Loess of the Wisconsin drift formation: Jour. Geology, vol. 4, pp. 929–937, 1896.

The "east bluff" (the quartzite bluff east of the lake), 1,560 feet above the sea level and 800 feet above the valley of the Wisconsin, 5 miles to the south, has a goodly development of clay loam (5 or 6 feet) upon it. This is exposed in but few places, but the sturdy character of the forest shows that there must be some soil other than that which could have arisen from the decomposition of the quartzite. At the spot where the problematical gravel heretofore described occurs the gravel overlying the quartzite is covered by 5 or 6 feet of nearly stoneless clay loam. Its aspect is such as to suggest its genetic connection with the loess. This loam, or something very like it, whatever its origin, is widespread. Whatever is true of the extraglacial surface loams, that which overlies the drift about Baraboo seems to belong with that which overlies the drift at Green Lake and which so frequently grades toward normal loess and sometimes assumes the character typical of that formation. I now believe it to be the equivalent of the stoneless, or well-nigh stoneless, mantle of clay which occurs at some points about Madison and which I was formerly inclined to regard as wind-blown dust accumulated on the ice and deposited in the final melting. In the adequacy of this suggestion I have less confidence than formerly. The phenomenon to be explained is widespread and may involve a much bolder hypothesis.

Kilbourn.—Occurrences noted by the present writer in the vicinity of Kilbourn have significant relations to the glacial formations. Along the road between Kilbourn and Elephants Back, a hill 2½ miles north of the town, 1 to 8 feet of buff noncalcareous loess coats the surface of the sandstone, which forms a flat plain or terrace east of the river. It is thought probable that the river meandered over this terrace and removed the outwash material while locating itself after the draining of Lake Wisconsin. On this terrace near its south end stands the city of Kilbourn. Along the railway southeastward from the station 5 to 8 feet of this loess-like loam overlies the sandstone. Near the first crossing south of town an excavation shows scattered crystalline pebbles and crystalline pebbles and bowlders lying on the surface of the sandstone beneath 5 feet of this loess loam. On the southeast, across the ravine, at the "Station 1 mile" post the following significant series is exposed:

Exposure of drift near Chicago, Minneapolis & St. Paul Railway 1 mile southeast of Kilbourn.

	Feet.
Buff noncalcareous clay (loess)	5–8
Sand and glacial gravel (outwash)	3–4
Highly calcareous reddish laminated clay (glacio-lacustrine)	3–4
Cambrian sandstone.	

Estimate of the lithologic composition of the gravel and comparison with a similar estimate of the pebbles of the terminal moraine three-fourths of a mile farther southeast show the material to be practically the same. This exposure is in an eroded slope due to excavation of the ravine and the neighboring river valley in the outwash terrace, and the thin bed of gravel is the remnant of the outwash over the rock at this point. From the relation here it is clear that the loess was deposited after the ice had withdrawn from the terminal moraine and the overflow from the lake had cut the river valley through the moraine. A few rods southeast the loess has a thickness of 15 feet and is somewhat more sandy in the lower half. At this point the outwash sand and gravel are not well exposed, if present, and the lake clay is absent from the surface of the sandstone, perhaps having been removed by erosion.

The face of the cut through the moraine is somewhat obscured by slumping, but a coating of 2 to 3 feet of loess seems to extend about halfway up the east slope of the ravine, which here borders the front of the moraine. Farther southeast, where the surface of the moraine appears to have been lowered by erosion, the mantle of clayey loess is more clearly defined, has a thickness of 5 to 6 feet, and extends northward up the slope over the surface of the moraine. One mile west of the railroad crossing, which is near the bend in the river, 10 feet of buff loess overlies 40 feet of loose sand and gravel mantling the top and sides of the point of the slope through which the cut is made between two ravines. There can thus be no doubt that the deposition of the loess has taken place since the river valley was cut through the moraine. Some large bowlders on the surface of the gravels are enveloped in the basal part of the loess, one a 6-foot quartz porphyry, another a gabbro with a 4-inch zone of disintegration about a sound core. It is not thought, however, that all this disintegration took place between the time of erosion of the slope and the deposition of the loess. It may have been initiated earlier and has undoubtedly continued since. This bed of loess resembles very closely the typical loess so widely distributed along the valleys of the Mississippi and its tributaries. It is buff in color with brownish banding, not the distinct banding of lamination but a banding due to a difference in tint perhaps resulting from a difference in texture that affected the degree of oxidation. It is massive and has a rude columnar cleavage that enables it to stand with vertical or even overhanging face. It is very porous though it stands so firmly without crumbling. Application of acid shows it to be noncalcareous. Under the microscope it is seen to be composed principally of very fine angular or slightly worn particles of various minerals, mostly quartz, with intermingled larger though still very fine grains of rounded quartz sand. The material as a whole is distinctly coarser and the particles are more worn than those of the glacio-lacustrine clays. It is a deposit of fine siliceous dust and looks as though it might have been blown up from the sandy plain to the west before vegetation had gained a foothold thereon. It is not generally present over the moraine; indeed, the deposits seem to be wholly local.

North of Baraboo.—A similar, but somewhat different, deposit of loesslike clay lies along the road and in a gravel pit near the cemeteries on the ridge north of Baraboo. At the gravel pit, where it overlies stratified morainal gravel, it has a thickness of 5 to 7 feet, is horizontally bedded in the lower part, and is slightly calcareous. From the pit it extends northward over the top of the ridge. On the slopes there is more or less well-defined bedding. The deposit here is partly below what was probably the highest level of glacial Lake Baraboo, and a part of the deposition may have occurred when the lake extended eastward, following the retreat of the ice front.

Delton.—Just south of the south bridge at Delton the road cut exposes noncalcareous loesslike loam, clayey in the upper part and more sandy and stratified below. Enveloped in this just above the top of the sandstone are some crystalline bowlders and cherts, the former probably dropped from ice floating in Lake Wisconsin, the latter probably residual. The loamy clay extends thence southward on the flat and up over the hill, where, at an elevation of 1,000 feet above sea level, it overlies the gravel noted on page 228.

Reedsburg.—Two and one-half miles southeast of Reedsburg (NE. ¼ sec. 23, T. 12 N., R. 4 E.) a 50-foot gully exposes loesslike buff loamy clay grading into stratified clay and stratified sand and clay. At one point 35 feet from the top is a bed of disk-shaped sandstone pebbles and chert fragments with no foreign pebbles. The lake occupying the Baraboo basin had a depth of about 200 feet near the steep slope on which this deposit lies. The lower 80 feet or so of this slope now lies beneath the lacustrine plain and the top of this deposit is marked by small terrace-like shelves (on which the road is situated) at 950 to 960 feet above sea level, or near what was probably the main water level in the lake. The stratified lower part of the deposit, including the gravel, is probably a lake-shore deposit, and the upper loesslike part is the final sedimentation of the finer silts suspended in the lake water or a subsequent eolian deposit.

Prairie du Sac.—A deposit of loesslike loam similar to that near Baraboo is exposed on the surface of the terminal moraine in a road cut 2 miles northeast of Prairie du Sac, just east of the north end of Blackhawk Bluff. The deposit, of which a thickness of 10 feet is exposed, is somewhat calcareous below a depth of 5 feet. It looks as though this loess might have been dropped where the wind eddied about in the lee of the north end of the ridge.

Oregon.—One mile south of Oregon a railway cut exposed 3 to 5 feet of buff, nearly stoneless clay, separated very distinctly from an underlying reddish, very stony till. The pebbles in the two beds differ notably in amount, though there are some in the upper clay, possibly incorporated from the surface of the till when the upper clay, which is clearly a distinct deposit, was laid down. Some of these basic pebbles are disintegrated. Tests with acid give no response to a depth of 10 feet, the maximum thickness of the clay. This is an unusual depth for leaching of the Wisconsin drift, even where, as here, it is loose and sandy. Very likely the upper clay was noncalcareous when laid down. This deposit may be loess originating under conditions similar to those noted above after the disappearance of the ice sheet.

Columbus.—Good exposures of loess are afforded by the cuts along the line of the Chicago, Milwaukee & St. Paul Railway in T. 11 N., R. 12 E. (Fountain Prairie Township) and T. 10 N., R. 13 E. (Elba Township), northwest and east of Columbus. At the viaduct on the line between secs. 10 and 20, Fountain Prairie, there is exposed the following section (see Pl. XXXV, *B*, p. 314):

Section of drift 3 miles northwest of Fall River.

	Ft.	in.
Buff porous noncalcareous loess with columnar structure, somewhat sandy at the top in places	3–6	
In places brownish sand	1	0
In places interlaminated sand and clay		4
Bowldery till, in places largely a mass of limestone fragments	10–20	
Lower Magnesian limestone.		

At the viaduct one-half mile southeast of the above location the railway cuts through an 18-foot ridge of gravel with till on the west side. Loess overlaps the whole, thinning to a few inches or less at the top and thickening to 6 feet on the slopes. On the slope of the gravel a few pebbles are included in the lower part of the loess, as though washed down during the early part of the loess deposition. In all the cuts the till below the loess is fresh and unweathered, indicating that no considerable time elapsed between the deposition of the drift and its mantling with the loess. Loess is not present in all the cuts, but where it occurs it is usually very thin on the crests of swells and thickens down the slopes to 3 or 6 feet, particularly on the east slopes, which would be the lee side when westerly winds were blowing.

One-half mile southeast of Doylestown the till exposed in the railway cut is overlain by 5 to 12 feet of sand and sandy clay (loess) of which the lower three-fourths is banded.

Dodge County.—Cuts examined by the writer in 1911 along the new line of the Chicago & Northwestern Railway, in Beaver Dam, Lowell, Clyman, and Lebanon townships, Dodge County, showed the brownish loamy clay very generally mantling the glacial drift of the drumlins. Most of the cuts seen were through drumlins. The loam has a thickness of 1 to 3 feet, usually being thin at the crest of the drumlins and thickening gradually down the sides lopes. It is commonly somewhat thicker on the east slope. In no place was typical loess seen. Where very thin the loam is not readily distinguished from the weathered surficial part of the till, from which most of the limestone pebbles have been removed by solution.

Ripon.—At one of Fred Lueck's sand pits at the top of the bluff west of the Ceresco Valley, at Ripon, the sandstone is overlain by a banded sandy loess. This is not the distinct lamination of water deposition but a more indefinite banding such as that of wind action.

Green Lake.—Salisbury [1] describes loess observed by him in Green Lake County as follows:

> Loess occurs in at least two localities near Green Lake, in Green Lake County. One of these points is about 2 miles northeast of the village of Dartford in the SW. ¼ sec. 10, T. 16, R. 13 E., where the loess is worked as molding sand for brass foundries. The loess here was not seen to contain shells or concretions, and is calcareous only at its base, and there but slightly. Its texture is fairly normal. It is exposed to the depth of 8 or 10 feet. The loess at this point is between 150 and 200 feet above Green Lake, and near the crest of one of the many high ridges of the region, the summits of which represent an old base-plain. Its substratum is till of the Wisconsin formation.
>
> The other point where loess is found is at the west end of the lake in sec. 4, T. 15, R. 12 E. The loess here is at a lower level, and on a slope which faces the lake. As in the other case, it overlies the drift of the Wisconsin formation. The loess at this second locality is of greater thickness than at the first, and is normal in texture, color, structure, and composition. It is calcareous, and has the roughly columnar structure which frequently characterizes loess exposed in vertical faces, and contains both the common types of gastropod shells, and calcareous concretions, though neither is plentiful. Its character is in every way such as to allow of no doubt of its being normal loess. Near its base it is interstratified with gravel.
>
> The loess in the vicinity of Green Lake is of special interest, not only because of its association with the deposits of the last glacial epoch, but also because its relations show, in at least one of the two localities, that it is not the work of wind.

Salisbury also describes the super-till loam about Green Lake and makes suggestions similar to those of the present writer (p. 341) in regard to its connection with the loess.

Analyses of loess.—Comparison of the results of mechanical analyses of loess (Nos. 6, 7, 8, p. 322) with those of rock flour from the glacial till (Nos. 4, 5) and a similar analyses of lacustrine clay (No. 1) shows that the loess on the Wisconsin drift in Columbia County is very similar in texture to that from Bridgeport near the mouth of Wisconsin River and to the mixture of loess loams from the Baraboo region. It is somewhat finer than the rock flour from the till but not so fine as the lacustrine silt.

[1] Salisbury, R. D., op. cit., pp. 930-932.

FOSSILS.

The following notes concerning remains of extinct Quaternary vertebrates which have been found in the area under discussion have been prepared at the request of the writer by O. P. Hay.

TAYASSU LENIS.

In his report on the upper Mississippi lead region J. D. Whitney [1] reported remains of an extinct peccary which he had found in a lead crevice at Blue Mounds. Three molar teeth were secured which Jeffries Wyman pronounced different from either of the fossil species but which resembled the existing peccary. It is therefore probable that these teeth were those of the extinct species described later by Leidy under the name of *Dicotyles lenis*, now to be known as *Tayassu lenis*.

BISON BISON?

In the lead crevice explored by J. D. Whitney at Blue Mounds, as already mentioned, were found some remains of a bison. Jeffries Wyman [2] gave a list of these bones, as follows: The upper portion of a right femur without head and trochanter; a right metatarsal bone; a calcaneum; a first phalanx of one of the feet. These were all of the size of the corresponding parts of the existing bison and closely resembled them. The bison is usually supposed to be a late comer into the Mississippi Valley, but this occurrence would appear to indicate an earlier arrival, though probably after the Wisconsin stage.

CERVUS CANADENSIS.

In the public museum at Milwaukee are parts of antlers of the American elk, which were found at two places in eastern Wisconsin. A part of an antler was found at Wauwatosa, Milwaukee County, at a depth of 4 feet. An antler was plowed up near Pewaukee, Waukesha County. It must, of course, have been near the surface. It is highly probable that both specimens belong to the Recent epoch.

MAMMUT AMERICANUM.

J. D. Whitney [2] reported the discovery of bones of the mastodon in a lead crevice at Blue Mounds, Dane County. With these were found remains of the peccary, a bison supposed to be the one now existing in North America, and a wolf, supposed to be the coyote. The remains were found in such circumstances that Whitney thought that without doubt all the animals had lived together. The depth at which they were found was not known, but he thought it might have been as much as 40 feet. They were embedded in yellow clay loam, the usual crevice earth.

There appears to be no good reason for supposing that all the animals found in the lead crevices of Iowa, Wisconsin, and Illinois may not have lived after the Wisconsin stage.

The mastodon remains consisted of fragments of the skull of a very young mastodon; of three small molars or milk teeth, possibly belonging to the skull just mentioned; of two teeth of an adult mastodon; of the two femora of a very young mastodon, possibly of the same young individual already mentioned; and finally of a foot bone of an adult. Whitney stated that the three milk teeth were in an exquisitely perfect state of preservation and were not at all discolored.

Various remains in the public museum at Milwaukee appear to belong to a mastodon. These were dug up November 12, 1878, by F. S. Perkins and F. Wells, in the township of Dover, Racine County. The tusks were both present, one of which was saved. There were several vertebræ, ribs, and some fragments of a scapula. No teeth were found. In the same museum there is a slightly worn last upper molar of a mastodon, which was found somewhere near or at Waukesha.

ELEPHAS PRIMIGENIUS.

In 1898 many bones of this animal were dug up in the western part of Milwaukee and are now in the public museum of that city. The remains were found on what is now Cold Springs Avenue, between Twenty-ninth and Thirtieth streets, at a depth of 13 feet. As this locality had been formerly used by circuses, it was supposed that a circus elephant had been buried there; but the bones are those of the hairy mammoth. In the same museum is a part of the upper jaw of a mammoth, apparently *E. primigenius*, which contains four teeth, the next to the last and the last molars of each side. The next to the last molars are worn down close to the roots; but the hindermost

[1] Wisconsin Geol. Survey, vol. 1, p. 136, 1862.
[2] Idem, p. 421.

molars had just begun to wear. These were found in Milwaukee, on the south side.

UNDETERMINED PROBOSCIDEANS.

C. A. Davis, of the United States Geological Survey, reported that in 1908 he collected parts of a tusk, small bones, and fragments of bones belonging to either the mastodon or the mammoth, that were washed out of a lake at Madison, Wis., by the hydraulic pumps in filling one of the city parks. Mr. Davis also collected in 1908, a short distance north of Fond du Lac, in the banks of a ditch, some of the smaller leg bones of a proboscidean. These and the fragmentary remains found by him at Madison he turned over to the University of Wisconsin.

Eliot Blackwelder states in a letter that the collection at the University of Wisconsin contains a proboscidean vertebra which in 1906 was dredged out of Lake Monona.

CANIS OCCIDENTALIS.

In the lead-bearing crevice of Blue Mound Whitney found the remains of a wolf, parts of jaws with teeth, and some limb bones. These were examined by Jeffries Wyman, who reported that he could not distinguish them from corresponding parts of the existing species of gray wolf.

In another crevice, but probably not at Blue Mound, was found a part of a skull containing most of the teeth. This appeared to belong to *Canis latrans*, the prairie wolf or coyote.

INDEX.

H.

I.

J.

K.

N.

O.

P.

O