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CHARLES D. WALCOTT, DIRECTOR

THE DELAVAN LOBE OF THE LAKE MICHIGAN GLACIER OF THE WISCONSIN STAGE OF GLACIATION AND ASSOCIATED PHENOMENA

BY

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WASHINGTON

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LETTER OF TRANSMITTAL.

DEPARTMENT OF THE INTERIOR,
UNITED STATES GEOLOGICAL SURVEY,
Washington, D. C., May 10, 1904.

SIR: I have the honor to transmit herewith the manuscript of a paper entitled "Delavan Lobe of the Lake Michigan Glacier of the Late Wisconsin Stage of Glaciation, and Associated Phenomena," by William C. Alden.

The manuscript has been read and approved by Prof. T. C. Chamberlin, geologist in charge of the section of Pleistocene geology, and I therefore recommend that it be published as a professional paper.

Very respectfully,

C. W. HAYES,
Geologist in Charge of Geology.

Hon. CHARLES D. WALCOTT,
Director United States Geological Survey.

THE DELAVAN LOBE OF THE LAKE MICHIGAN GLACIER OF THE WISCONSIN STAGE OF GLACIATION AND ASSOCIATED PHENOMENA.

By William C. Alden.

INTRODUCTION.

The purpose of this paper is to throw, if possible, some further light on the relations which existed during the later stages of the Glacial epoch between the glaciers of southeastern Wisconsin, which have been so ably discussed by Dr. T. C. Chamberlin and other writers in various publications, and the glaciers of Illinois, which have received such exhaustive treatment by Mr. Frank Leverett in his recent monograph on the Illinois glacial lobe.

So familiar are the students of Pleistocene geology with the work in the Wisconsin and Illinois fields that it is unnecessary to undertake at this time an exhaustive historical résumé of the results attained, even if the space limitations of this paper would permit. The writer has been engaged during several seasons, under the direction of Dr. T. C. Chamberlin, in investigating the Pleistocene deposits and associated phenomena of southeastern Wisconsin for the United States Geological Survey. The results of this investigation are to be embodied in a series of folios of the Geologic Atlas of the United States. A portion of these results are here presented for the first time. Whatever of value may pertain to these studies is due in very large measure to the intelligent direction, the kindly criticism, and the hearty cooperation of Dr. T. C. Chamberlin, with whom the writer has kept in close touch through personal conference and frequent correspondence during the progress of the work. In the main, the writer is responsible for the field observations, for the final correlation of the details, and for this presentation. For correlations beyond the immediate area studied by the writer, previous publications have been freely drawn upon. There are also a large number of persons who have furnished information or assistance during the progress of the field work to whom the writer wishes to express his obligations.

It may be well to make brief mention concerning the names proposed for the several morainic belts discussed. Heretofore these have been grouped together under the general name "Kettle Range," or "Kettle moraine." The features grouped under one or both of these names have been defined by Prof. T. C. Chamberlin as follows:[a]

"*Kettle Range.*—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. The northern terminus of the range lies in the town of Casco, Kewaunee County. From this point it stretches away to the southwestward, through the counties of Manitowoc, Sheboygan, Fond du Lac, Waukesha, and into the northern portion of Walworth. At this point it divides, one portion extending southward, through the towns of Richmond and Darien, thence eastward to Lake Geneva, whence the main portion extends northeastward to the vicinity of Burlington, and then southward into Illinois. The other portion, branching from the main range in the town of Whitewater, about 20 miles north of the State line, extends westward to the Rock River, after crossing which it curves to the northward. * * *"

After the definite recognition of two distinct stages of glaciation, a first and a second glacial epoch, the name "Kettle moraine" was given a more extended application, as shown by the following:[b]

"*The Kettle moraine.*—The most striking result of the second glacial advance was the production along the margin of the ice sheet of a great moraine, the most gigantic and remarkable yet known to characterize glacial action. It consists of a great ridged belt of drift disposed in grand loops along what was the glacier's margin. Its reentrant angles penetrated deeply between the adjoining lobes, marking their line of contact. 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 similar accumulations, the term 'Kettle moraine' may fittingly be applied to it."

Continuing, in a footnote, in the same connection, Professor Chamberlin says:

"It should be remarked in this connection that there are two or more concentric moraines, constituting a belt, rather than a single moraine. These are often forced into contact and confusion, so that their distinct discrimination is impracticable, while at other points they are quite distinct, and separated by several miles distance. It is proposed to apply the name 'Kettle moraine' to the outermost member, when clearly distinguishable, and to extend its use, or that of the term 'Kettle Range,' to the entire group where they are confused so as to be indistinguishable. The Kettle

[a] Geol. Wisconsin, vol. 2, 1877, pp. 205-206.

[b] Geol. Wisconsin, vol. 1, 1882, p. 275.

moraine, therefore, designates the morainic ridge produced by the extreme advance of later glaciation. Names for the inner moraines are not here proposed because, although distinguishable in Wisconsin, as indicated in Volumes II and III, they are displayed in greater distinctness and definition elsewhere, especially in Minnesota and Dakota, from some of the characteristic localities of which it is proper that fitting names should be selected, and such will be announced, if not sooner proposed, in connection with the results of the wider studies of the writer upon the formation now in progress."

Thus far, with the exception of the Lake Border morainic system, these several inner belts have not been definitely correlated with those of neighboring States. In working out the details of the local geological history it is important that many of these features, such as the several moraines of the small lobe under discussion, should be discriminated, but they have not any considerable geographic extent, and hence should be designated by local names, and these have been proposed where it seemed necessary. The same procedure has been followed in the discussion of the several morainic members included by Professor Chamberlin under the name "Kettle moraine" or "Kettle Range." That portion of the general morainic system which lies between and was formed by the joint action of the Green Bay and Lake Michigan glaciers is referred to descriptively in this paper as the "interlobate Kettle moraine," it not being thought desirable at this stage of the investigation to propose a more definite name.

For convenience of reference the following outline of the stages of glaciation and intervals of deglaciation thus far recognized by the United States Geological Survey is here inserted. This outline is modified from that given by Mr. Frank Leverett in his recent monograph on the "Glacial Formations and Drainage Features of the Erie and Ohio Basins,"[a] and is based upon the latest data from the studies of Prof. T. C. Chamberlin, Mr. Frank Leverett, and many other students of glacial phenomena. The principal modification consists in the substitution of the phenomena of the late Wisconsin drift sheets as developed in Wisconsin and Illinois for those represented in the Ohio district.

Outline of drift sheets and intervals.

1. Oldest recognized drift sheet, the sub-Aftonian of Chamberlin, and perhaps the Albertan of Dawson.
2. First interval of deglaciation, Aftonian of Chamberlin.
3. Kansan drift sheet of the Iowa geologists.
4. Second or Yarmouth interval of recession or deglaciation.
5. Illinoian drift sheet.
6. Third or Sangamon interval of recession or deglaciation.
7. Iowan drift sheet and main loess deposit.

[a] Leverett, Frank, The glacial formations and drainage features of the Erie and Ohio basins: Mon. U. S. Geol. Survey, vol. 38, 1899, pp. 21-22.

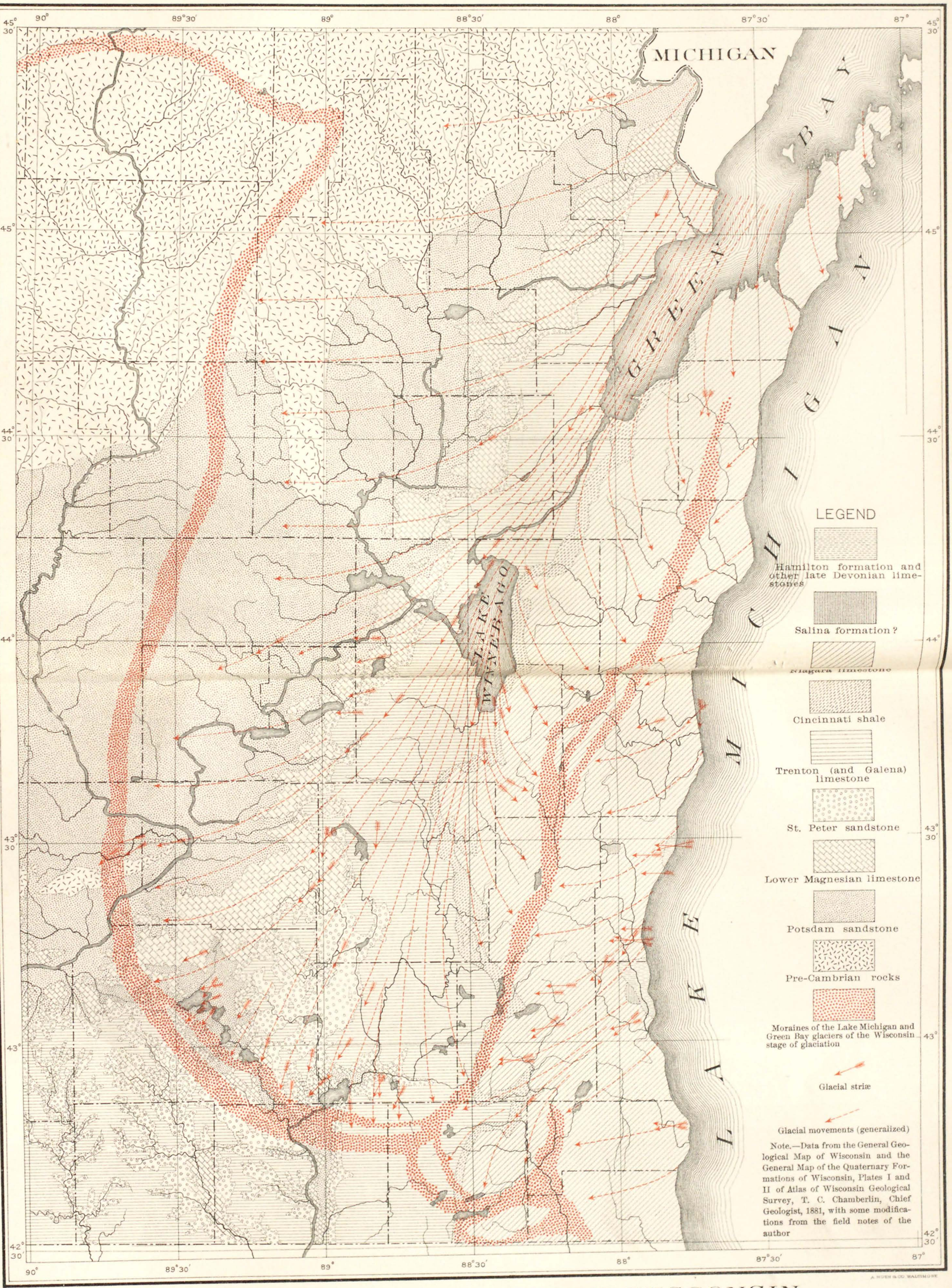
8. Fourth or Peorian interval of recession or deglaciation.
9. Early Wisconsin drift sheets, as represented in Illinois.
   a. Shelbyville morainic system.
   b. Champaign morainic system.
   c. Bloomington morainic system.
   d. Marseilles morainic system.
   (With one of these four morainic systems, possibly the third, is to be correlated the Marengo Ridge of western McHenry County, Ill.)
10. Fifth interval of recession (unnamed), shown by shifting of the ice lobes.
11. Late Wisconsin drift sheet, as represented in Illinois and in southeastern Wisconsin.
   a. Great bowlder belts and accompanying moraines, including, perhaps, the Minooka, Ill., till ridge.
   b. Valparaiso morainic system of the Lake Michigan Glacier. { Genoa, Darien, Elkhorn, and other morainal deposits of the Delavan lobe of the Lake Michigan Glacier. Johnstown, Milton, Hebron, and certain other morainal deposits of the Green Bay Glacier. }
   c. Lake-border morainic system.
   (No further correlations with the moraines of the Green Bay Glacier have yet been made.)
   d. Lake Chicago submergence, Glenwood stage.
   e. Emergence of plain covered by Lake Chicago.
   f. Partial resubmergence of the plain covered by Lake Chicago, Calumet stage.
   g. Possible second interval of emergence.
   h. Partial resubmergence of the plain covered by Lake Chicago, Toleston stage.
   i. Present stage of Lake Michigan.

DESCRIPTION OF THE AREA.

GEOGRAPHIC RELATIONS.

The area under discussion lies principally in southeastern Wisconsin, where it embraces Racine, Kenosha, and Walworth counties, and adjacent parts of Milwaukee, Waukesha, Jefferson, Rock, and Dane counties, an area somewhat greater than 2,000 square miles. It includes also a small portion of northeastern Illinois adjacent to the State line. In this area are developed certain glacial phenomena which throw some light on the relations existing between the glaciers of Illinois and Wisconsin during the earlier and later advances of the Wisconsin stage of glaciation. The special feature of this discussion is the Delavan lobe of the Lake Michigan Glacier, which thrust itself out between the converging west front of the Lake Michigan Glacier and the south front of the Green Bay Glacier a distance of 25 miles beyond the main west front of the Lake Michigan Glacier.

On the one hand, this Delavan lobe was an integral part of the Lake Michigan Glacier of the late Wisconsin advance, and, on the other, the relations of its morainal and outwash deposits to those of the Green Bay Glacier appear to



GEOLOGIC MAP OF EASTERN WISCONSIN

SHOWING THE RELATIONS OF THE MOVEMENTS AND DEPOSITS OF THE GLACIERS OF THE WISCONSIN STAGE OF GLACIATION TO THE UNDERLYING FORMATIONS

BY

WILLIAM C. ALDEN

Scale

0 10 20 30 40 50 miles

1903

establish beyond question the contemporaneity of the Lake Michigan and Green Bay glaciers in the occupancy of their outer terminal moraines.

Thus the outer terminal moraine of this Delavan lobe, instead of being the northward continuation of the Marengo Ridge of the early Wisconsin series, as would appear from the statements of some writers, seems to cross the latter ridge near the west end of Lake Geneva in passing eastward to join the Valparaiso terminal morainic system of the main Lake Michigan Glacier in the region south of Burlington, Wis.

GEOLOGICAL STRUCTURE AND PRE-GLACIAL TOPOGRAPHY.

In order to understand the conditions of the development of this Delavan lobe and to fully appreciate the significance of the determinations of the lithological character of the drift, it is necessary to consider briefly the geological structure of the region and the pre-Glacial and pre-Wisconsin topography. Pl. I shows the geological structure of the eastern half of the State and the distribution and directions of movement of the Green Bay and Lake Michigan glaciers of the late Wisconsin stage.

In this discussion the names of the several Paleozoic formations are used as in the Geology of Wisconsin, with the exception that those beds provisionally referred to the Lower Helderberg formation by Professor Chamberlin are now regarded as belonging to the Salina formation. Reference to these formations being merely incidental to the discussion of the drift features of the area, it is not considered advisable to discuss the proposed revision of the nomenclature.

In the northwestern part of the area shown on Pl. I are the pre-Cambrian highlands, composed of Archean and Huronian rocks. Lapping upon the eastern and southeastern slope of this nucleus are the Paleozoic formations, beginning with the Potsdam sandstone, of Cambrian age, and ending with the Hamilton beds, of Devonian age. These formations have easterly and southeasterly dips. As shown by the section of the Blue Mounds west of Madison, the Niagara and all the subjacent formations originally extended far beyond their present limits, if not quite across the southern part of the State. At present the Niagara formation, with the exception of a few small outlying remnants, is confined to a belt 40 to 50 miles in width bordering the shore of Lake Michigan. It is evident that pre-Glacial erosion denuded the eastern half of the State of hundreds of feet of rock. In consequence of this extensive denudation, the western marginal parts of the several rock formations of this part of the State outcrop in more or less irregular belts, generally parallel to one another, to the strike of the beds, and to the west shore of Lake Michigan. Thus, in traversing the area from west to east one ascends the geological scale. The following is the list of formations present:

Geological formations of southern Wisconsin.

Devonian period.
- Hamilton formation.
  - (Cement rock, blue and black shale.)

Silurian period.
- Salina formation.
  - (Thin-bedded, dolomitic limestone.)
- Niagara limestone.

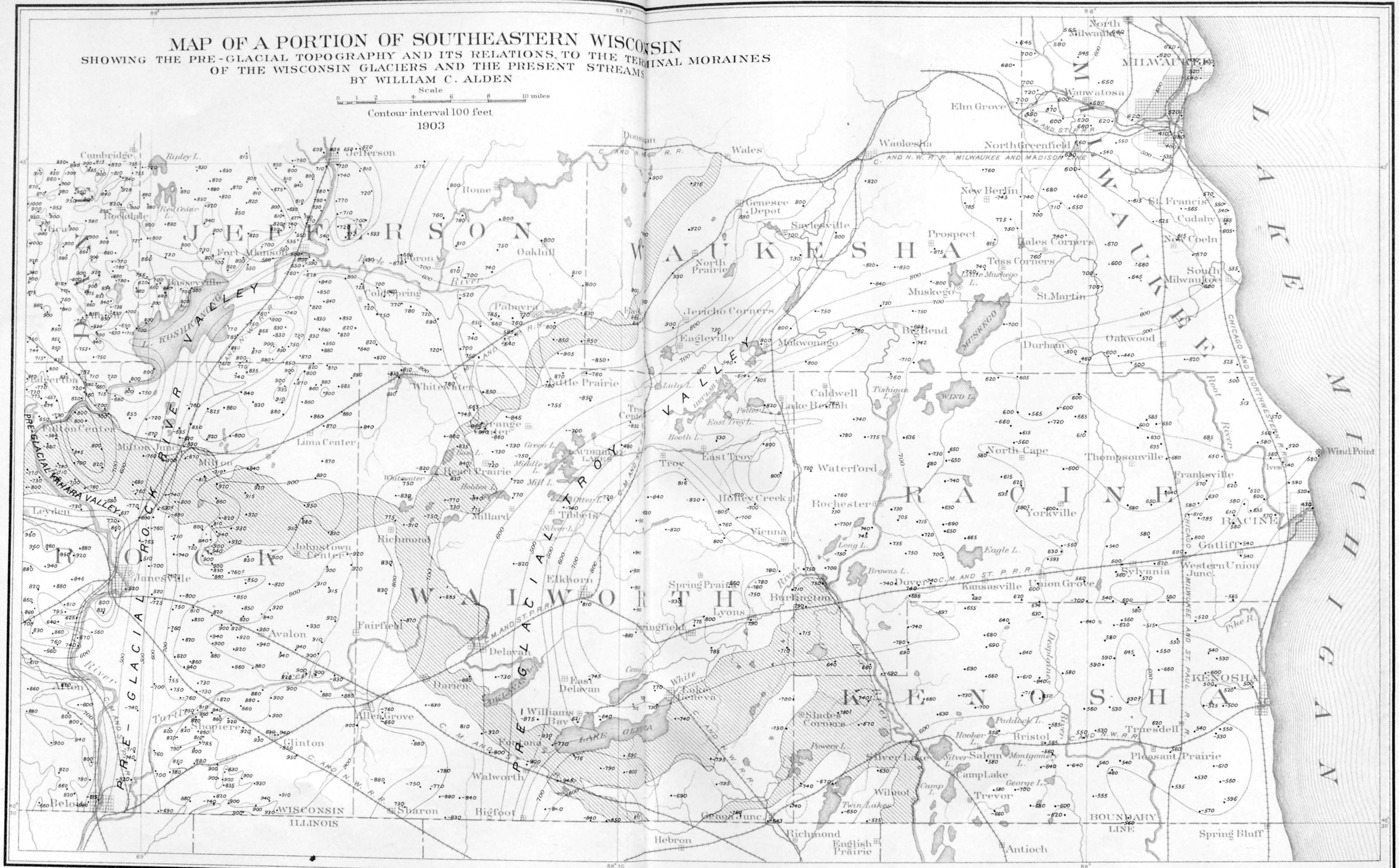
Ordovician period.
- Cincinnati shale.
- Galena limestone.
- Trenton limestone.
- St. Peter sandstone.
- Lower Magnesian limestone.

Cambrian period.
- Potsdam sandstone.

Pre-Cambrian.
- Huronian quartzite.
- Igneous and metamorphic rocks.

The formation having the greatest influence on the deployment of the glaciers of eastern Wisconsin during the late Wisconsin invasion was the Cincinnati shale. This formation has an average thickness of about 200 feet, and is composed in its upper part chiefly of slightly indurated clay shales and limestones, while in the lower horizon are arenaceous and thin-splitting, brittle, slaty shales. As the result of this composition, wherever the heavy superjacent beds of Niagara dolomite were removed by erosion the poorly indurated beds of this formation were readily removed, and the erosion, thus localized, extended downward into subjacent Galena beds. A broad trough was thus formed, its bottom and long west slope of Galena limestone, and its east side a more or less abrupt escarpment in the beds of the Cincinnati group and the thick overlying beds of the Niagara group. On the borders of Green Bay and Lake Winnebago this escarpment rises to a height of about 400 feet above the rock bottom of the trough. Farther south the valley shallows by the thinning of the west margin of the Niagara formation and the less sharp erosion of the Cincinnati beds. Moreover, the region is so heavily covered with drift that even the exact location of the west margin of the Niagara and Cincinnati formations can not always be ascertained.

Owing to the extent to which the older drift formations of the State are covered by the later deposits, it is not evident to what degree this Green Bay-Lake Winnebago trough influenced the advance of the glaciers of the earlier stages. It is plainly evident, however, that this trough determined the direction of the flow of the Green Bay Glacier of the late Wisconsin stage, if, indeed, to



LEGEND

Areas of the outer terminal moraines of the Green Bay Glacier, and of the Lake Michigan Glacier, including the Delavan lobe

•580 Figures give the elevation of the rock surface above the sea level at the points indicated, as shown by outcrops and well borings

•-730 Figures preceded by a dash indicate that the rock surface lies at unknown depths below the levels reached by the wells at the points so marked

Note.—Elevations approximate, determined from the U. S. G. S. topographic maps it was not due the actual differentiation of this part of the great ice sheet as a distinct glacial lobe. So also to the tributary valleys leading into this trough in southern Waukesha and Walworth counties was due the development of the Delavan glacial lobe, with the consideration of which this paper has to do.

The pre-Glacial topography, or, more properly speaking, the configuration of the rock surface beneath the drift, within the limits of the area treated in this paper, is shown on Pl. II with such accuracy and detail as the data at hand will permit. The terminal moraines of the late Wisconsin glaciers and the courses of the present streams are also traced, to show the relations.

The pre-Glacial Rock River Valley, in Rock County, contains 300 to 400 or more feet of drift. South of the Johnstown moraine the surface of the outwash deposit filling the valley is nearly flat. This surface rises from an elevation of 800 feet above the sea at the State line to 900 feet at the front of the moraine. The higher parts of the undulating tracts on the east and the west of this valley reach an elevation of 1,000 feet above the sea, so that the location of the broad valley and its tributaries is plainly marked. From the front of the moraine to Lake Koshkonong there are 400 feet or more of drift in the morainal belts which cross the valley, so that the presence of the pre-Glacial trough would hardly be suspected.

The rock first reached in the well[a] at the Rock County farm, 4 miles north of Janesville, is the Lower Magnesian limestone in the west slope of the pre-Glacial valley, at an elevation of about 635 feet above tide. In the Riverside farm artesian well, about 2 miles southwest of the city, the rock first struck, at an elevation of 560 feet above sea level, belongs to the same formation. In the fair grounds well and the water company's wells at Janesville the red shale of the Potsdam group was the first rock struck in the lower valley slope, at elevations of about 510 and 520 feet, respectively. No deep wells south of the moraine are so located as to reach the bottom of the valley, so that the full depth can only be conjectured. The elevation of this bottom is evidently less than 450 feet above the sea, but may not be below 400 feet at the State line. Professors Chamberlin and Salisbury, in their article on the driftless area of the upper Mississippi,[b] cite the fact that a well on the border of Lake Koshkonong shows the valley bottom to be at least 330 feet below the present level of Rock River, or only about 450 feet above the ocean. One well in the valley at Fort

[a] Elevations determined from topographic maps of United States Geological Survey.

Authorities for well records: Rock County farm well and Riverside farm well, E. Hindes, driller, Janesville, Wis.; Janesville fair grounds well, Geology of Wisconsin, vol. 2, p. 166; wells of Janesville Water Company, records at company's office; wells in Fort Atkinson and vicinity, data from Albert Hummell, driller, ex-Governor Hoard, McMillen Bros., Carl A. Becker, Mr. Bullock, Dewitt Wilcox, O. A. Howard, G. J. Hausz, Henry Ehlers, and Peter Young; well in Scuppernong Marsh, Robert Blackmore, driller, Palmyra, Wis.

[b] Chamberlin, T. C., and Salisbury, R. D., Preliminary paper on the driftless area of the upper Mississippi Valley: Sixth Ann. Rept. U. S. Geol. Survey, 1886, p. 223.

Atkinson, about 30 miles north of the State line, was reported as having reached the Potsdam sandstone in the bottom of the valley at an elevation of about 500 feet above sea level, while several wells in the same vicinity reach the rock at elevations ranging from 500 to 560 feet. These wells penetrated 200 to 330 feet of drift. Seven or 8 miles east of this place a well in the Scuppernong Marsh is said to have penetrated 270 feet of drift—i. e., to an elevation of 520 feet above the sea—without reaching the bottom of the valley. North of the moraine there is 200 to 330 feet of filling, and the valley is occupied by Lake Koshkonong and extensive marsh areas. The relations of the present stream to the pre-Glacial valley are shown on Pl. II.

East of the pre-Glacial Rock River Valley, and separated from it by a broad ridge of rock, is a broad valley that owes its location to the slight induration of the Cincinnati beds. The upper branches of this valley are traversed by Fox River between Waukesha and Big Bend, but the main valley contains no stream of importance. Since the position of the pre-Glacial valley is now most plainly marked by the low area within and adjacent to the towns of Troy and East Troy, in northeastern Walworth County, it may be conveniently referred to as Troy Valley.

The low tract in the adjacent parts of Waukesha and Walworth counties lies 100 to 200 feet lower than the crest of the Kettle Range and the undulating ground moraine tracts on the south, yet the pre-Glacial valley is so largely filled with morainal and outwashed drift, and the surface of this drift presents such a peculiar topography, that it scarcely impresses one as marking the position of a definite river valley. The present topography is that of 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 in depth, with abrupt gravel slopes, and occupied by marshy tracts and by more than a score of ponds and lakelets. Several wells show that the basin marks the location of a pre-Glacial valley cut through the marginal beds of Niagara limestone and those of the Cincinnati group. In Mr. Fred Andrews's well, 1¾ miles southwest of the village of Mukwonago, the first rock reached was shale at an elevation of about 540 feet above sea level. Upon this shale was 300 feet of drift. In Mr. Stephen F. Fields's well, 1 mile east of East Troy, the Galena limestone was the first rock struck, at an elevation of 530 feet above the sea, beneath 330 feet of drift; while McKee Brothers' well, 5 miles west of East Troy, penetrated 401 feet of drift before reaching limestone at an elevation of 480 feet. [a]

[a] Authorities for well records:

Andrews's well, Otto Hembrook, driller, Mukwonago; Fields's well, Arthur Smith, Burlington, in whose possession were samples of drillings, McKee Brothers' well, W. L. Thorne, driller, Whitewater.

While it is clear from these well records that there is here a very considerable pre-Glacial valley, the position of its outlet is somewhat open to conjecture. The valley appears to be too deep to have discharged into Rock River Valley by way of the valley between Palmyra and Fort Atkinson, now occupied by Scuppernong Creek and Marsh; moreover, the limestone has been reached at a sufficient number of points beneath the Kettle moraine and the outwash deposits on the east to make it almost certain that a continuous rock ridge 200 to 300 feet high separates the two basins. Like reasons appear to exclude connection with the valleys tributary to Rock River Valley in eastern Rock County. It seems to be equally sure that there was not an eastward discharge to the Lake Michigan basin. The most probable line of discharge is southward through Walworth County, as shown on Pl. II, yet this mapping is based on the general relations rather than on positive evidence furnished by the area itself. It was reported to the writer that a certain well 3 or 4 miles southeast of the village of Darien 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 at this place lies lower than 600 feet above tide.

At Elkhorn the city well entered the Cincinnati beds without any overlying Niagara limestone being encountered, whence it appears that the west margin of the Niagara formations lies east of that point. The removal of this protecting limestone must have exposed the underlying shale to extensive erosion west of Elkhorn, the same as farther north. That the shale was so eroded beneath the Lake Geneva basin to the south 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 621 feet above the sea. Though the shale is usually 200 feet or more in thickness, 177 feet being penetrated by the Elkhorn well, but 33 feet were found overlying the Galena limestone at this point. It thus appears probable that the course of the Troy Valley is as shown on Pl. II.

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, as there seems little reason to doubt, there must be from 400 to 600 feet of drift piled into it within the Darien moraine. The further extension of the Troy Valley to the south is doubtless beneath Big Foot Prairie, southward through McHenry County, Ill., where it may have joined the pre-Glacial Kishwaukee Valley, to which reference is made by Mr. Frank Leverett,[a]

[a] The Illinois glacial lobe: Mon. U. S. Geol. Survey, vol. 38, 1899, p. 485.

and its waters discharged to the old Rock River Valley somewhere south of Rockford.

Wells in the area surrounding Lake Geneva show that the lake lies in a partly filled pre-Glacial valley whose bottom is less than 640 feet above the sea—i. e., more than 220 feet below the present lake surface, or about 80 feet below the lake bottom at its deepest point. This valley evidently discharged westward, thus being tributary to the Troy Valley.

OLDER OR PRE-WISCONSIN DRIFT.

The relations of the drift deposited by the glacier of the later Wisconsin stage to that of the glaciers of earlier stages in southern Wisconsin, Illinois, and Iowa, and western Indiana, are shown on Pl. III. These relations are discussed in detail by Mr. Leverett in his monograph on the Illinois glacial lobe and need not be described here except as they affect the specific phenomena discussed in this paper. So far as the writer's investigations have extended, there is little or no decisive evidence as to the exact age of the pre-Wisconsin drift of southern Wisconsin, though it appears probable from Mr. Leverett's studies in Illinois that drift of the Illinoian stage, and possibly of the Iowan stage, is here represented.

That this so-called "older drift" is really older than the moraine-bordered drift was long ago shown by Professor Chamberlin and his associates of the Wisconsin and the United States geological surveys.[a]

The evidence of greater age is found in the greater depth of leaching and oxidation of the drift, in the greater degree of weathering of the surface bowlders, and in the greater amount of erosion and more advanced stage of development of drainage systems of these extra-morainal tracts than in the moraine-bordered areas.

All these tests are specifically applicable to the older drift of southeastern Rock County and southwestern Walworth County, which is the most closely related of the pre-Wisconsin drift sheets, in point of situation, to the deposits of the Green Bay Glacier and of the Delavan glacial lobe. The older drift is thoroughly leached of its calcareous elements to a depth of 3 or 4 feet, sometimes to a depth of 5 feet or more. Oxidation extends to a considerable depth, and the upper 3 or 4 feet is stained to a brownish or yellowish-brown color. Very generally the color of the upper one-half foot to 1½ feet of the drift is bleached to a dirty gray, and several inches of black humus usually coats the whole. Within the moraine-bordered areas the leaching occasionally extends to

[a] Geol. Wisconsin, vol. 1, 1882, pp. 271–272.

depths of 3 or 4 feet, but the depth is usually between 1 and 2 feet, while the oxidation is less marked than in the older drift.

The crystalline bowlders of the later drift area usually show little indication of disintegration, while the occasional blocks of Niagara dolomite are nearly as fresh in appearance as if just taken from the quarry. In the older drift area the occasional Niagara bowlders will hardly be recognized at first glance. Their granular weathered surfaces are dull grayish to buff, often made grotesquely irregular by deep solution pits, which in some cases extend nearly or quite through the blocks. It is only on fresh fracture that the familiar whitish, crystalline character of the Niagara limestone is seen. Incipient cracks frequently appear in the crystalline bowlders, and it is very common for light blows of the hammer to flake off shell-like pieces one-eighth to one-fourth of an inch thick from their rounded surfaces.

The erosional difference is also notable; the later drift surface shows very little post-Glacial modification. Marshes, lakes, and ponds abound. The topography is everywhere of the depositional type. Large tracts of easily eroded material show absolutely no erosional modification other than the slightest surface gullying. In the older drift area erosion has made considerable progress. Nowhere is there the thorough dissection seen in the oldest drift sheets; the topography is still very young, yet numerous little valleys, 1 to 3 miles in length, show 40 to 60 feet of erosion. Some of the tributaries reach back 10 to 11 miles, and the whole area is well drained.

On the other hand, all these evidences of atmospheric exposure fall far short of those shown in the oldest drift sheets. The degree of leaching and oxidation is moderate. The crystalline pebbles and bowlders in the body of the drift, with the occasional exception of the more basic varieties, are usually compact and solid. Even where some of the basic bowlders have disintegrated, the component minerals are but slightly decomposed. The pebbles of Niagara limestone are fresh and clean, while considerable gently undulating areas have not been trenched by erosion.

Considering these facts, it appears that the drift in question probably occupies a position in the series somewhere between the Kansan and the Wisconsin drift sheets—i. e., it is probably either Illinoian or Iowan. Mr. Leverett, who has wide acquaintance with the drift phenomena of the Mississippi basin, has correlated the upper part of this drift with the Iowan stage of glaciation. The reasons for this correlation are, he says—

"because of an apparent similarity with the Iowan drift of eastern Iowa in its connection with the great sheet of loess in the Mississippi basin. The loess overlaps this drift sheet only a short distance in Illinois and was deposited apparently while the ice sheet was melting away, there being no clear evidence of an exposure of its till to protracted atmospheric action prior to the deposition of the loess."[a]

Concerning the thickness of the Iowa drift Mr. Leverett states[b] that in eastern Winnebago and Boone counties, Ill., the drift of Iowan age is known to have considerable thickness, possibly an average of 40 feet or more. On the whole, however, he considers it a liberal estimate to allow an average of 10 feet, both of till and of loess, as the product of the Iowan invasion in Illinois. Below this occurs the Illinoian drift.

In the southeastern part of Rock County, Wis., numerous exposures of the underlying rocks occur, and often wells find less than 40 feet of drift; but, on the other hand, many other wells show more than 100 feet of drift. In southwestern Walworth County thicknesses of 200 to 250 feet are known to occur. It is quite possible that here, as in Illinois, these thicknesses comprise two or more drift sheets.

The prevailing color of the older drift in the area east of Rock River is pinkish at the surface exposures, but at greater or less depths a more solid blue till is encountered. One well 3 miles southwest of Clinton Junction penetrated solid blue clay which was so dense and dry that it was necessary to pour in water to wet the drill until a gravel stratum was reached at a depth of 100 feet. Some wells penetrate considerable deposits of sand or gravel between thick deposits of clay. Others penetrate deposits of black muck. But sufficient accurate data have not yet been collected to show beyond doubt that these are the deposits of an interval of deglaciation separating two distinct drift sheets.

PEORIAN STAGE OF RECESSION OR DEGLACIATION.

PEORIAN SOIL HORIZON.

Mr. Leverett states[c] that extensive deposits of muck and peat occur in the base of the Wisconsin drift in northern Illinois, notably in McHenry, Dekalb, Lasalle, and Bureau counties, which are in all probability immediately underlain, in some cases at least, by Iowan drift. The early Wisconsin drift sheets have been so far overridden by the late Wisconsin glaciers in southeastern Wisconsin that clear evidence of the Peorian stage of deglaciation has not been found.

The occurrence of soil horizons and vegetal remains has been reported at a few points beneath the terminal moraine, and outwash deposits of the Green Bay and Delavan glaciers; but it is by no means certain that they were formed

[a] Leverett, Frank, The Illinois glacial lobe: Mon. U. S. Geol. Survey, vol. 38, 1899, p. 130.
[b] Op. cit., pp. 136 and 137.
[c] Op. cit., pp. 185-186.

during the Peorian interval. In their article on the driftless area,[a] Messrs. Chamberlin and Salisbury make the following reference to inter-Glacial deposits in this region, based on information furnished by Mr. Reynolds, of Johnstown:

"Beneath the overwash gravels that fringe the moraine in the Rock River Valley, there are considerable accumulations of vegetable matter. The wells of Johnstown, Rock County, sunk at various times during the last thirty years, have frequently penetrated these. The maximum depth charged with vegetable matter is several feet."

A well near the edge of the moraine, 4½ miles northeast of Johnstown Center, penetrated the following deposits:

Section of well near Johnstown Center, Wis.

	Feet.
Top soil	1
Quick sand and gravel	10
Blue clay	40
Gravel	179
Black soil	2
Limestone	18
Total	250

The "black soil" resting on the limestone may be pre-Glacial rather than inter-Glacial.

Mr. W. H. Featherstone's well on the extreme frontal margin of the Darien moraine, 3 miles northwest of Walworth, penetrated the following deposits:

Section of the Featherstone well, near Walworth, Wis.

	Feet.
Clay	6
Reddish gravel	18 to 20
Yellow sand	2
Hard blue clay	42 to 44
Black quicksand	7 to 8
Total	80

The water from the "black quicksand" tasted like marsh water and was said to have had at first a very disagreeable odor. The margin of the Darien moraine of the late Wisconsin glacier at this point overlaps the older drift with no intervening outwash and, so far as known, with no interpolated drift of early Wisconsin age. The well curb stands but 20 or 30 feet above the level of the older drift outside of the moraine, so that it is quite as possible that the black humus marks the Sangamon soil horizon as that it was deposited during the Peorian interval.

[a] Chamberlin, T. C., and Salisbury, R. D., Preliminary paper on the driftless area of the upper Mississippi Valley: Sixth Ann. Rept. U. S. Geol. Survey, 1886, p. 264.

WISCONSIN STAGE.

EARLY WISCONSIN GLACIATION.

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 Pl. III, which is compiled from data obtained by Mr. Leverett. These successive drift sheets so overlap in the northern part of the State that, in northern Kane County, the Bloomington and Marseilles moraines 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.

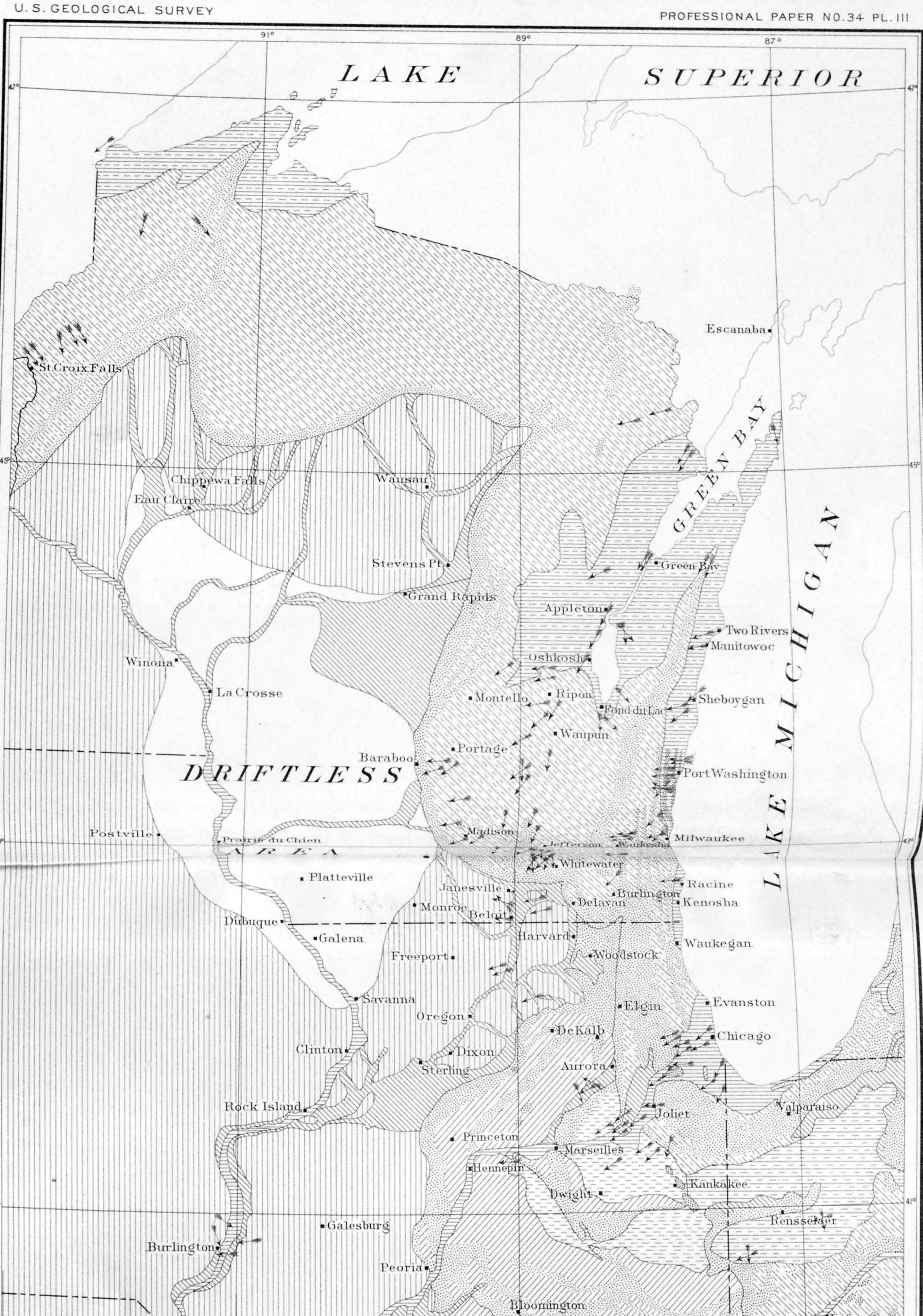
Near the village of Hampshire, in northwestern Kane County, the Marengo Ridge passes by the eastern end of the outer ridge of the Bloomington morainic system in a course nearly normal to it, and thence northward to the vicinity of Walworth, Wis., a distance of 30 to 35 miles, constitutes the outer moraine of the early Wisconsin series.[a] Mr. Leverett states[b] 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 overriden; 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 moraine.

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 correlations Mr. Leverett writes in part as follows:[c]

"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.

[a] Leverett, Frank, The Illinois glacial lobe: Mon. U. S. Geol. Survey, vol. 38, 1899, p. 290.
[b] Op. cit., pp. 295-296.
[c] Op. cit., pp. 302-304.



LEGEND

Probable temporary lake areas

Lake Kankakee

Lake Chicago area, so far as correlation has been made; outlets of lakes Chicago, Agassiz, and Maumee

Red pebbly clays (partly lacustrine, partly probably glacio-lacustrine) and associated lacustrine deposits not fully correlated with the deposits of Lake Chicago

Sand and gravel plains and terraces, mostly outwash deposits of Wisconsin age, including some lacustrine deposits

Late Wisconsin drift sheets

Early Wisconsin drift sheets

Glacial ridges, chiefly moraines of the Wisconsin glaciers

Pre-Wisconsin drift

Driftless, except on the northern borders of the area

Glacial striæ

Note.—Data for that part of the glaciated area of southeastern Wisconsin lying south of latitude 43° N., also for that part of the lake-border region of Wisconsin, south of latitude 43° 30′ N., from the field notes of the author.

Data for the remainder of Wiscon- [illegible] nesota and Iowa, from the General Map of the Quaternary Formations of Wisconsin, Plate II, of Atlas of Wisconsin Geological Survey, T. C. Chamberlin, Chief Geologist, 1881, and from the Quaternary Map of the Driftless Area and Environs, by T. C. Chamberlin and R. D. Salisbury, Plate XXVII, of Sixth Annual Report U. S. Geological Survey, 1885.

Data for Illinois and adjacent parts of Indiana, Michigan, Iowa, and Missouri, from the Glacial Map of the Illinois Ice Lobe, by Frank Leverett, Plate VI, of Mon. U. S. Geological Survey, Vol. XXXVIII, 1899.

QUATERNARY MAP OF WISCONSIN, ILLINOIS, AND ADJACENT AREAS

BY

WILLIAM C. ALDEN

Scale

0 5 10 20 30 40 50 60 70 miles

1903

"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 as in this instance. * * *

"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 from this line."

He further suggests a combination of these interpretations by which the great bulk of the portion north of Elburn is referred to the Bloomington morainic system, while the slight moraine in southeastern Kane County is made the result of the late Wisconsin invasion, in which the ice would be supposed to override the composite belt without greatly modifying its character. The relation of the Kaneville esker northwest of Aurora, Ill., he thinks, however, 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 late Wisconsin age, to this composite morainal belt in the vicinity of the State line.

Near Elgin, Ill., the combined Marseilles moraine and Minooka Ridge separate from the eastern part of this composite belt. In Kendall County this ridge divides into the component moraines, of which the Marseilles moraine is referred to the early Wisconsin group, while the Minooka Ridge is provisionally correlated with those of the late Wisconsin glacier. From northern Kendall County northward the Marseilles moraine appears to have been overridden by the later advance.

The equivalence of the Valparaiso morainic system to the eastern portion of the composite belt is established beyond doubt. Mr. Leverett states[a] 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.

[a] Op. cit., pp. 304-305.

RELATIONS BETWEEN THE MARENGO RIDGE AND COMPOSITE MORAINIC BELT IN ILLINOIS AND THE MORAINES OF THE DELAVAN GLACIAL LOBE IN WISCONSIN.

The relations of the moraines in northern Illinois being as above stated, it is of some importance to determine how the moraines of Wisconsin are related to the Marengo Ridge and the associated composite morainal belt. In brief, the relationship may be stated as follows:

The Marengo Ridge extends about 1½ miles into Wisconsin south of the head of Lake Geneva. Here it ends in a long north slope which appears to be due to its dropping down into the depression formed by the confluence of the pre-Glacial Geneva and Troy valleys (Pl. II).

Where the Darien moraine crosses this trough west of Lake Geneva, instead of being depressed its crest 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 (Pl. XIV). North of Williams Bay and the head of Lake Como, in the line of the continuation of this ridge, the deposits of the Elkhorn moraine reach the highest elevation in this part of the State—1,140 feet above the sea—though farther north this moraine is a very inconsiderable topographic feature.

From these facts it appears very probable that the 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 formation.

This ridge so largely filled Troy Valley near Walworth that, when the Darien moraine was deposited across the drift-filled valley, no depression of its crest occurred, but instead the crest was higher than to the northwest. The elevation north of Williams Bay is well accounted for by supposing that the Elkhorn moraine here crossed the Marengo Ridge as the latter ascends the pre-Glacial slope.

The Genoa, Darien, and Elkhorn moraines lie in curves transverse to the trend of the 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 late Wisconsin Glacier, which formed the transverse moraines.

The ice movement in the southern part of the Delavan lobe, as elsewhere shown, varied from a direction normal to that of the glaciers forming the earlier morainal systems to a direction oblique to that of the earlier movement. That is to say, while the early Wisconsin glacial movements were from east to west across Lake and McHenry counties, Ill., the direction of the movement of the southern part of the Delavan lobe of the late Wisconsin stage varied from south to southwest. The change in direction of movement in this small lobe of the late Wisconsin glacier was due to local conditions and is insignificant in comparison with the shifting of the axes of the great glacial lobes in Illinois. This is especially true when it is considered that the movement in the Lake Michigan Glacier across Racine and Kenosha counties, Wis., and Lake County, Ill., agreed with that of the earlier glaciers in being from east to west. Nevertheless it is worthy of note that in the southern half of Walworth County, Wis., there was a discordance between the movement in the Delavan lobe of the late Wisconsin Glacier and the movement of the early Wisconsin glaciers in northern Illinois, which discordance is in agreement with the shiftings of the ice lobes on a much grander scale in Illinois. It is on the basis of this shifting of the ice lobes in Illinois and Indiana that the distinction has been made between the earlier and later advances of the glaciers of the Wisconsin stage. There is no evidence of a great difference in age. It is not known to what extent the earlier glaciers of the Wisconsin stage wasted away before the readvance was inaugurated. Illinois was not improbably freed from ice, and the same may have been true of Wisconsin. The change in conditions appears to have been sufficient at least to result in the notable shifting of the ice lobes above mentioned.

LATE WISCONSIN GLACIATION.

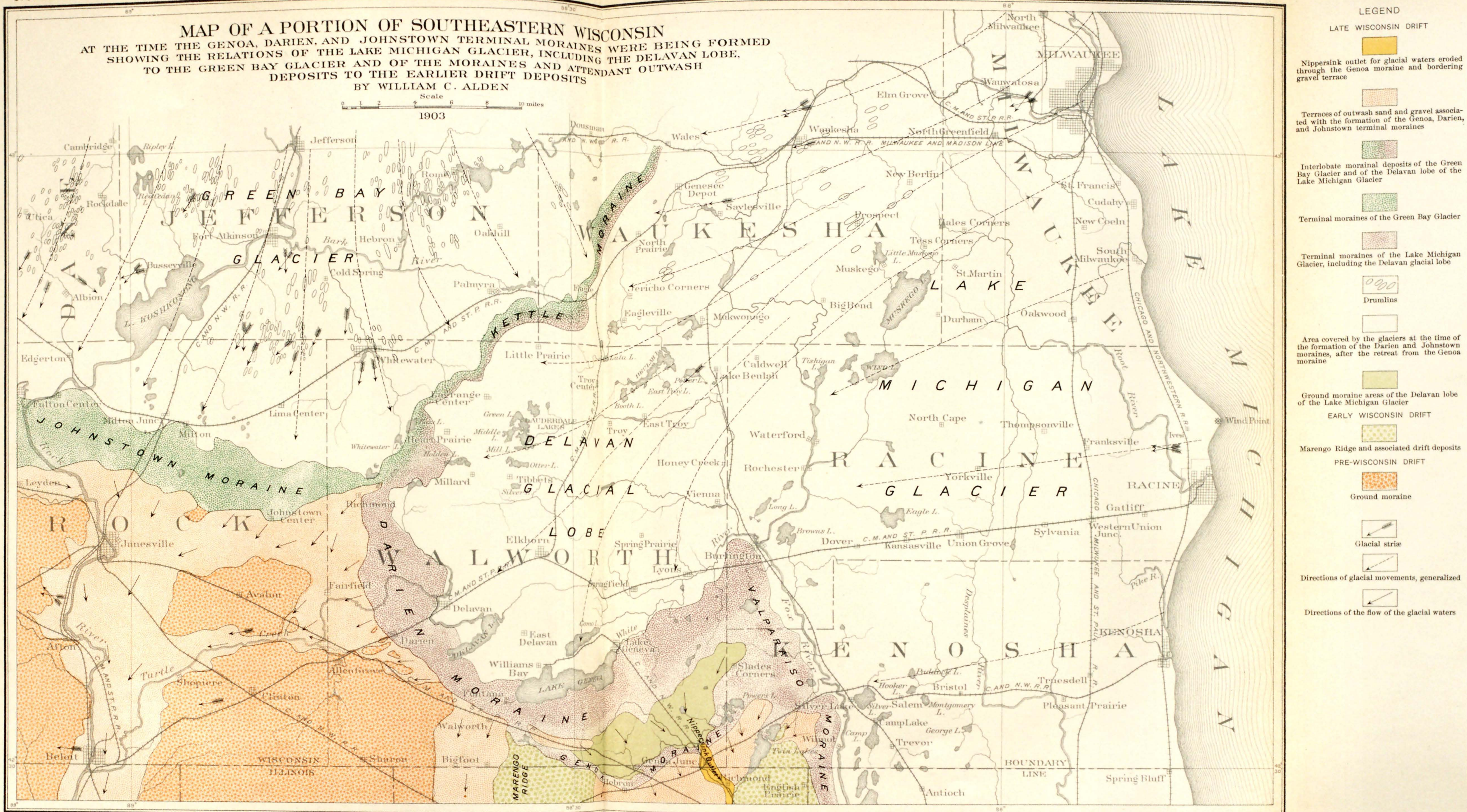
OUTLINE OF THE PROCESS OF GLACIATION AND DEGLACIATION OF THE AREA.

Before taking up the detailed discussion of the several moraines and associated outwash deposits of the late Wisconsin glaciers it may be well to give an outline of the history. It is not possible to determine in very much detail the history of the advance of the glaciers, because during the advance and subsequent melting of the ice the record was made obscure. Near the limit of the advance of the ice the deposits, not having been again overridden, are more readily deciphered, and, as much more of the record remains, the later history seems to be more complicated than the earlier. Whether it really was so may well be questioned.

The area covered by the late Wisconsin glaciers in Wisconsin and adjacent parts of the neighboring States at the time of their maximum extension is shown on Pl. III, and their extent in the part of southeastern Wisconsin under discussion is shown in more detail on Pl. IV. The fronts of the Green Bay and Lake Michigan glaciers were in conjunction along a line which ran northeastward from the vicinity of Richmond, and along this line was formed the interlobate Kettle moraine. Near Richmond the ice fronts diverged; that of the Green Bay Glacier lay along the Johnstown moraine to the west, and that of the Delavan lobe of the Lake Michigan Glacier lay along the Darien moraine southeastward to the vicinity of Walworth, and, beyond this, along the Genoa moraine, a branch of the main terminal moraine. The west front of the main Lake Michigan Glacier lay to the east, along the Valparaiso moraine, near the line of Fox River. From these melting ice fronts copious streams of water poured down the pre-Glacial Rock and Troy valleys, filling them with vast amounts of sand and gravel. While the ice fronts yet held their advanced positions through most of their extent, the south front of the Delavan lobe was melted back to the main terminal moraine, which lay south of Lake Geneva and ran thence northeastward to the vicinity of Burlington. The escaping waters then cut an outlet through the outer moraine near Genoa Junction, which is now occupied by Nippersink Creek.

On the completion of the Darien and Johnstown moraines, a stage of excessive wastage ensued, the marginal parts of both the Delavan and Green Bay lobes being eaten away. Whether the extent of this retreat of the ice fronts is measured by the distance between the outer moraines and those next formed, or whether there was a further retreat followed by a readvance to these moraines, is not known. At the next stage the glaciers appear to have had the extension shown on Pl. V. The margin of the Delavan lobe lay along the Elkhorn moraine, while the Green Bay Glacier occupied the Milton moraine, the junction of the two ice fronts having been moved to the vicinity of Lagrange Center, about 9 miles northeast of its former position. For about 3 miles along the front of the Green Bay Glacier the water discharged into the low area behind the Darien moraine, where it formed the outwash plain on which stands the village of Heart Prairie. This water and that from the west front of the Delavan lobe cut an outlet through the Darien moraine and the bordering gravel terrace and escaped to the newly formed Rock River. This latter stream originated when the water from the Green Bay Glacier, ponded behind the Johnstown moraine, broke over a sag in the morainal crest and began the erosion of a valley in the gravel plain along the line of the present stream. Probably about this time also lakes Geneva, Delavan, and Como were formed.

Again the rate of wastage gained the ascendency and the retreat of the ice fronts was resumed and the margin of the Delavan lobe was gradually forced back across the elevated area east of Elkhorn. (Pl. X.) A part of the waters escaped southward to the Nippersink outlet at Genoa Junction, while the rest escaped by the Turtle Creek outlet near Delavan. A part of this latter flow, probably concentrated by a sag in the drift, began the excavation of Sugar Creek Valley through the high area east of Elkhorn. The Green Bay Glacier still stood snugly pressed against the interlobate Kettle moraine at least as far south as Palmyra, though the ice on the east was melting away. The discharge of


MAP OF A PORTION OF SOUTHEASTERN WISCONSIN
AT THE TIME THE GENOA, DARIEN, AND JOHNSTOWN TERMINAL MORAINES WERE BEING FORMED
SHOWING THE RELATIONS OF THE LAKE MICHIGAN GLACIER, INCLUDING THE DELAVAN LOBE, TO THE GREEN BAY GLACIER AND OF THE MORAINES AND ATTENDANT OUTWASH DEPOSITS TO THE EARLIER DRIFT DEPOSITS
BY WILLIAM C. ALDEN
Scale
0 1 2 4 6 8 10 miles
1903
LEGEND
LATE WISCONSIN DRIFT
Nippersink outlet for glacial waters eroded through the Genoa moraine and bordering gravel terrace
Terraces of outwash sand and gravel associated with the formation of the Genoa, Darien, and Johnstown terminal moraines
Interlobate morainal deposits of the Green Bay Glacier and of the Delavan lobe of the Lake Michigan Glacier
Terminal moraines of the Green Bay Glacier
Terminal moraines of the Lake Michigan Glacier, including the Delavan glacial lobe
Drumlins
Area covered by the glaciers at the time of the formation of the Darien and Johnstown moraines, after the retreat from the Genoa moraine
Ground moraine areas of the Delavan lobe of the Lake Michigan Glacier
EARLY WISCONSIN DRIFT
Marengo Ridge and associated drift deposits
PRE-WISCONSIN DRIFT
Ground moraine
Glacial striæ
Directions of glacial movements, generalized
Directions of the flow of the glacial waters
GREEN BAY GLACIER
JEFFERSON
DANE
WAUKESHA
MILWAUKEE
LAKE MICHIGAN GLACIER
RACINE
KENOSHA
WALWORTH
ROCK
DELAVAN GLACIAL LOBE
KETTLE MORAINE
JOHNSTOWN MORAINE
DARIEN MORAINE
GENOA MORAINE
VALPARAISO MORAINE
MARENGO RIDGE
LAKE MICHIGAN
WISCONSIN
ILLINOIS
BOUNDARY LINE
Milwaukee
Waukesha
Jefferson
Janesville
Beloit
Racine
Kenosha
Delavan
Elkhorn
Burlington
Whitewater
Lake Geneva
Nippersink Outlet
A. HOEN & CO. BALTIMORE

waters from the converging ice fronts thus built up the first or upper terrace which borders the Kettle moraine on the east, from its junction with the Elkhorn moraine to a point 4 miles northeast of Eagle. West of Palmyra but meager morainal deposits are now exposed, so that the exact position of the south front of the Green Bay Glacier is in doubt.

The wasting of the glaciers continued until their margins had about the relations shown on Pl. XIII. As far north as the vicinity of Wales the Green Bay Glacier now ceased to pour its waters over the Kettle moraine into the province of the Delavan lobe on the east. Its southeast front perhaps lay along the moraine running northward from the vicinity of Palmyra. The waters from the Delavan lobe, having cut down the Sugar Creek Valley as low as the channel leading to the Turtle outlet, and the wasting of the ice having cleared the valley, a new outlet for the waters from the north was opened, allowing them to escape to the Nippersink outlet at Genoa Junction. This new channel having a greater fall than that by way of the Turtle outlet, the latter was abandoned and the accelerated flow cut away much of the morainal and terrace deposits east of Eagle and formed a second and lower terrace.

The formation of the third and lowest gravel terrace in southwestern Waukesha County and northeastern Walworth County, which marks the next distinct stage of the glacial retreat, occurred when the retreating margin of the Delavan lobe cleared the Fox River Valley as far north as Burlington and the valley of Honey Creek above the latter place, thus giving a new and still lower outlet for the glacial waters, which then began, with renewed energy, the excavation of the gravels of the second terrace. About this time the retreating front of the Green Bay Glacier must have made a stand at the Hebron moraine, its last halt within the area under discussion. The further history of the wasting of this glacier is not considered in this paper.

At length the Delavan lobe was entirely wasted away. This appears to have been accomplished while yet the west front of the main Lake Michigan Glacier occupied the Valparaiso morainic system bordering the line of the Fox River southward to the State line. From this time the whole west front of the Lake Michigan Glacier retreated eastward across the area. Stages in this retreat are marked by the ridges of the lake border morainic system.

With the withdrawal of the glacial margin into the basin of Lake Michigan the waters of a lake which occupied the basin, expanding as the ice disappeared, produced a series of phenomena which are discussed under the history of Lake Chicago (pp. 68–72). At the Glenwood stage the waters of this glacial lake stood about 60 feet higher than the present lake level and discharged through an outlet in the vicinity of Chicago, Ill. Following this was a low-water stage, due probably to the further retreat of the glacier and the opening of a lower outlet to the northeast. Following this low-water stage the waters again rose, this time to a level about 40 feet above the present lake. This constitutes the Calumet stage. Associated either with the Calumet stage or with the latter part of the Glenwood stage, a readvance of the glacier southward to the vicinity of Milwaukee is believed to have occurred. To the peculiar combination of conditions resulting from lake action and from the crowding of this glacier upon the land is referred the deposition of a red clay which overlies the lacustrine deposits from the vicinity of Milwaukee northward. Certain evidence has developed indicating the possible occurrence of a second low-water stage of Lake Chicago following the Calumet stage. At the final stage, the Toleston, the lake stood 20 feet or more higher than the present lake. The final opening of a northeast outlet lower than the Chicago outlet merged the history of Lake Chicago into that of Lake Michigan.

DEPLOYMENT OF THE GREEN BAY AND LAKE MICHIGAN GLACIERS AND THE ORIGIN OF THE DELAVAN LOBE.

As the ice of the later advance of the glaciers of the Wisconsin stage invaded the borders of Wisconsin, the troughs formed by the erosion of the soft beds of the Cincinnati formation became the controlling factor in the separation and deployment of the Green Bay Glacier, and, in the southeastern counties, in the formation of the Delavan lobe of the Lake Michigan Glacier. The pre-Glacial valleys seem not to have been obliterated by the earlier drift deposits.

While the Green Bay-Lake Winnebago trough was competent to give direction to the Green Bay Glacier, it was not sufficiently deep to confine the deployment of the glacier to its immediate limits. On the west the ice spread out 60 to 70 miles from the main axis of the lobe. In western Shawano County and eastern Marathon County, where the ice encroached upon the Archean highlands, the marginal deposits lie at an elevation nearly 1,000 feet higher than the bottom of Green Bay, opposite Sturgeon Bay. Farther south the ice, after ascending the gentle slope of the Galena formation, reached the southward and southwestward discharging valleys eroded in the St. Peter and Potsdam sandstones, which doubtless facilitated the advance in that direction, so that the ice extended to northern Rock County and northwestern Walworth County, where the Johnstown terminal moraine was formed.

On the east the deployment of the ice was confined to 20 to 30 miles from the axis of the lobe. This limitation was not, however, due to the escarpment formed by the west margin of the Niagara limestone and the underlying shales, since southward to southwestern Waukesha County the ice overrode the escarpment and began to descend the gentle eastward slope of the Niagara formation.

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 15 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 famous interlobate Kettle Range, or Kettle moraine, was formed.

In Illinois and Indiana the Valparaiso morainic system is 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, shown on Pl. II. 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 this pre-Glacial valley was filled with drift of the earlier ice invasions is not known, but that it offered a channel of easy flow to the ice nearing the limits of its advance on the gently rising slope of the Niagara formation is apparent from the fact that down this trough the ice advanced to the vicinity of the villages of Richmond, Darien, and Walworth, a position nearly 25 miles farther west than the limit reached in Illinois. The village of 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.

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 to the ice nearing the limit of its advance on the gently rising slope, 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.

DIRECTIONS OF ICE MOVEMENT IN THE GLACIERS.

Within the southern part of the area of the Green Bay Glacier the directions of the ice flow radiated toward the crescentic margin. The radiation is shown by the striæ on the rock, and more strikingly by the strongly developed drumlin topography of the ground moraine. In southwestern Waukesha County, northwestern Walworth County, and southeastern Jefferson County the direction varied from southeast to south, toward the interlobate Kettle moraine (Pl. IV). Some of the striæ observed in southern Jefferson County and in northeastern Rock County have a more southwesterly trend than the neighboring drumlins. It is possible that they were formed during an earlier glacial advance, or they may be merely local variations in the direction of the movement.

The directions of the ice movement in the Lake Michigan Glacier are shown by similar phenomena (Pls. IV and XIV). In Waukesha County, from the vicinity of the village of Genesee northward, the movement was westward toward the Kettle moraine. Striæ observed 1½ miles east of Genesee range from S. 80° W. to S. 94° W. Those seen at Hadfield's quarry, north of Waukesha, range from S. 58° W. to S. 81° W.

The southwestern diversion down Troy Valley is shown by obscure striæ observed by Professor Chamberlin[a] 3 miles south of Mukwonago which have a trend S. 45° W. to S. 50° W.; by the trend of the drumloidal hills and elongated ridges of the ground moraine of southeastern Waukesha County, which is S. 50° W. to S. 60° W., and by striæ observed in several exposures in the vicinity of Milwaukee which range from S. 19° W. to S. 71° W.

In Racine and Kenosha counties the movement was again more westerly. Striæ observed at Horlick's quarry, northwest of Racine, range from S. 83° W. to S. 93° W.

In the Delavan lobe, while the axial movement was southwestward, there was doubtless a fan-like deployment of the ice such as occurred on a much grander scale in the Green Bay Glacier. This is indicated by the looped disposition of the moraines, but unfortunately there are no rock exposures so situated as to demonstrate the divergent movement. Certain drift ridges between the villages of East Troy and Waterford have a more southerly trend than the striæ observed south of Mukwonago, as though the flow was there diverging toward the south.

Certain disturbances in the rock layers observed by Professor Chamberlin[b] at the quarry west of Burlington indicate that the direction of the ice movement there was southerly.

OUTER TERMINAL MORAINES AND ASSOCIATED PHENOMENA.

GENOA TERMINAL MORAINE.

The Genoa moraine should probably be considered a branch of the Darien moraine. Northwest of the head of Lake Geneva the latter marks the limit of the advance of the Delavan lobe. The ice front appears to have continued here after it had withdrawn from the Genoa moraine to that part of the Darien moraine east of the head of Lake Geneva.

[a] Geol. Wisconsin, vol. 2, p. 204. [b] Op. cit, p. 204.

Excepting that part within 3 miles of Genoa Junction, the Genoa moraine has a weak and rather equivocal development. It is the strong development near Genoa Junction which gives the name to the moraine. In Southern Walworth County, as has been indicated, the bulky Marengo Ridge ends in a long north slope where it drops down into the pre-Glacial Troy Valley at its junction with the pre-Glacial Geneva Valley. Beginning at a point 1 mile south of the village of Walworth a narrow and fairly well-defined belt of morainal topography is seen bordering the east margin of Big Foot Prairie. This belt may be traced up the slope to the south and thence southward as the crest of the Marengo Ridge. A short distance east of the northern extremity of this belt a second, milder belt of sags and swells, with occasional well-marked gravel knolls and kettle holes, separates from the main part of the Darien moraine, south of the western end of Lake Geneva, and may be traced with some discontinuity southeastward across the State line to the village of Hebron, Ill. One and one-half miles northwest of Hebron the valley of Nippersink Creek, which to the northeast and to the southwest is marked by broad marshy flats, is occupied by a deposit of morainal gravels. From the vicinity of Hebron this belt may be traced eastward and northeastward into Wisconsin again, along the south border of the marshy valley of Nippersink Creek. One-half mile north of Genoa Junction it is cut through by the creek.

From the second crossing of the State line to the valley of Nippersink Creek, near Genoa Junction, the Genoa moraine is strongly developed. The abrupt, ice-contact face rises 60 to 80 feet above the marshy tract on the north, and its crest is broken by abrupt knolls and ridges of gravel alternating with kettles, many of which are large and deep. In the vicinity of Hebron, Ill., several wells within this belt have penetrated 60 to 70 feet, principally of gravels. One well, west of Genoa Junction, penetrated 139 feet, principally sand and gravel. East of Nippersink Creek the moraine may be traced northeastward for a mile by a narrow gravel ridge pitted with kettles, which forms the crest of a broader ridge apparently of till. Beyond this, again, the moraine is not so well defined.

In western Kenosha County 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, two of them occupied by Power and Lilly lakes. Within these depressions, surrounding them, or alternating with them, are equally irregular hills, ridges, and hummocky deposits of gravel. Reliefs of 60 to 100 feet are frequent.

In the interlobate angle in southwestern Kenosha County, between the converging south front of the Delavan lobe and west front of the Lake Michigan

Glacier, morainal, outwash, and earlier ground moraine deposits are so confusedly distributed that it is difficult to say just what were the extreme limits of the Lake Michigan Glacier in this vicinity at this stage, but there can be little doubt that its west front occupied that part of the Valparaiso morainic system which, for some distance southward, lies west of Fox River.

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 this correlation can not be far from correct. The strongly developed moraine and accompanying outwash apron extending westward from the vicinity of Genoa Junction was unquestionably formed along the south front of a glacier, and the mild morainal deposits which have been described are in the line of the most probable continuation of this morainal belt. At one point, about 4 miles southeast of Walworth, it was noted that a small drainage line in the north slope of the Marengo Ridge was blocked by the morainal deposits of the Genoa substage so as to inclose a small pond and marsh. A very slight morainal crest runs off to the southward from the vicinity of Hebron, Ill., but this is nearly normal to the trend of the Genoa moraine, is bordered on the west by an outwash deposit, and appears to belong to the earlier Wisconsin series.

If the ice front occupied the Darien moraine between Walworth and Richmond while the Genoa moraine was being formed, it continued its occupancy after it had withdrawn from the Genoa moraine to that part of the Darien moraine between Walworth and Burlington. The Darien moraine appears to be one continuous deposit.

OUTWASH DEPOSITS.

The disposition of the water resulting from the melting of the late Wisconsin glaciers was one of the most important features of this stage of glaciation. The glacial drainage 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 of the several successive stages. The character and amount of this outwash material during the Wisconsin stage indicate a vigorous and long-continued flow.

The converging Genoa and Valparaiso moraines in southwestern Kenosha County have more or less continuous, though very irregular, ice-contact slopes, from the crests of which outwash deposits decline toward the Twin Lake depression, where they are not always to be distinguished from the morainal and till deposits.

From the valley of Nippersink Creek at Genoa Junction to a point nearly 2 miles west of Hebron, Ill., the Genoa moraine is bordered on the south by an extensive deposit of sands and gravels which are frequently exposed beneath a thin coating of clay.

ABANDONMENT OF THE GENOA MORAINE AND RELATIONS OF THE ICE FRONTS.

The deposition of the Genoa moraine and accompanying outwash deposits was 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 that part of the Darien moraine lying 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 interlobate moraine, while the south front of the Green Bay Glacier stood at the outer or Johnstown moraine. In western Kenosha County the west front of the main Lake Michigan Glacier still occupied the morainal belt west of Fox River, though the angle of junction with the south front of the Delavan lobe was shifted northward to a position not far from the southwest corner of Racine County. The distribution of these moraines is shown in Pl. IV.

DARIEN TERMINAL 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 the outer margin of the moraine near the most southwesterly point reached by the Delavan lobe. The distribution of this moraine is shown on Pl. IV.

This 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 this relief is but 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 morainal system, south of Burlington, there is no regular outer slope, but the deposit is largely 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, excepting the Delavan Lake basin and small eroded valleys on the north and south, there is no definite inner slope and but 20 to 60 feet relief. At several places the terminal-moraine topography passes 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. This is 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 gentle 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 gravel knolls 15 to 40 feet in height occur. 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 quite generally a strongly marked knob-and-kettle topography, where humps and hollows are closely crowded and 30° slopes and abrupt reliefs of 40 to 100 feet are not infrequent. Here and there are small basins, utilized as fields, surrounded by abrupt winding ridges of gravel. Eastward across 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. 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 outlet through the latter moraine at Genoa Junction.

At the head of the Geneva basin there is a sag in the Darien moraine, at an elevation of 1,000 feet, or 140 feet above the level of the lake, but neither the sag nor the surface of the outwash plain gives evidence of the passage of much water outward from the lake basin. Two miles north of the village of Darien the moraine is cut by a broad valley, which varies in width from one-half mile to 1½ miles. Its broad, flat bottom, through which winds Turtle Creek, lies 80 to 100 feet below the adjacent higher parts of the moraine. 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 the existence of a sag in the moraine at this point which doubtless determined the location of the valley.

Judging from the surface exposures and the well records obtained, this morainal belt is mostly composed of sand and gravel. A well in the ridge south of Lake Geneva is 329 feet deep; of this at least 300 feet is in blue-clay till. A considerable part of the bulky deposit may have been formed at an earlier stage of glaciation.

JOHNSTOWN TERMINAL MORAINE.

Extending westward from the vicinity of Richmond, near which point the fronts of the Delavan lobe and the Green Bay Glacier diverged, is the Johnstown terminal moraine of the Green Bay Glacier. This moraine is so designated because the villages of Johnstown and Johnstown Center, in eastern Rock County, are situated near the most southerly points reached by the ice at this stage. The width of this moraine varies from three-fourths of a mile near Richmond to nearly 5 miles farther west.

Bordering this moraine on the south is an extensive outwash plain, from which the front of the moraine rises rapidly in places, but generally with gentle slope, 40 to 140 feet, to the undulating crest line, which varies in altitude between 920 to 1,060 feet above the sea. In general the inner and outer slopes are much the same, but on entering Walworth County from the west, as the interlobate angle is approached, the moraine narrows and the inner face becomes abrupt and high.

In its surface contours this morainic belt is somewhat variable. Considerable areas of the inner half of the moraine have the gentle undulations of the ground moraine, with slight sags and swells here and there. The surface is generally rougher in the outer half, where gravel knolls and kettles frequently occur. In general the surface contours of both the Johnstown and Darien moraines are much the same. More or less ice was buried in the morainal drift, as is evinced by the sags and kettles, yet the intricate topography of the interlobate moraine is not to be found. This difference between the topography of the frontal and that of the interlobate moraines is general throughout the area and may be, in part at least, the result of the difference in the conditions under which the ice melted. Along the frontal margins when the ice melted the water flowed immediately away from the ice front in separate streamlets, washing the gravels as it went, so that there was less chance of burial of ice masses before they were melted. Between the contiguous ice slopes of an interlobate tract the water of the two glaciers united to form a considerable stream, which flowed along the intervening trough, washing the gravels over frequent and considerable masses of ice before they had time to melt. In the interlobate tracts there was doubtless considerable pushing up of morainal material into an intricate series of heaps and ridges as the result of forward crowding of the contiguous ice fronts after intervals during which they had been melted back slightly in certain parts. Along the frontal margins such oscillations would probably be of the nature of overriding rather than of plowing up or pushing up.

The surface exposures of this moraine are very largely of till, but the records of the wells indicate that the great bulk is of sand and gravel. Fifteen wells ranging in depth from 120 to 238 feet, concerning which information was obtained, were reported as almost entirely in sand and gravel after penetrating the superficial coating of till.

Where the Johnstown moraine crossed the pre-Glacial Rock Valley southwest of Milton Junction, the crest lowers and a notable break occurs, forming the sag which is traversed by the Chicago and Northwestern Railway. This break is not wholly, at least, due to erosion, since its bottom is marked by inclosed depressions, the largest of which extends 100 feet below the level of the bordering outwash plain.

About 5 miles farther west, where the moraine crosses the pre-Glacial Catfish or Yahara Valley, the present Rock River has cut its channel. Two narrow breaks in the morainal crest near Richmond appear to have afforded temporary outlets for the water ponded behind the moraine after the withdrawal of the ice from the crest.

INTERLOBATE DEPOSITS.

For nearly 7 miles northeastward from the village of Richmond the Darien and Johnstown moraines are combined into an interlobate deposit varying in width from $1\frac{1}{4}$ to 3 miles. Beyond this the Kettle moraine consists of one indivisible moraine extending northeastward, which bears the impress of a later stage, though it is probable that the deposition of the constituent material was begun while the Darien and Johnstown moraines were being formed.

On the west side of this interlobate tract the slope rises abruptly from the depressions in which lie Number 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. There has been considerable subsequent filling behind the Darien moraine, but the eastern crest still stands 40 to 60 feet above the plain on the east. Farther south, where there has been less filling, there is an abrupt ice-contact face of 80 to 120 feet relief. The crest on this side, which is also pitted with depressions, marks the Darien moraine.

Near Richmond the Johnstown crest is the higher of the two, but farther north this crest lowers somewhat and the Darien crest gains the ascendency. From the latter a flat resembling an outwash apron declines gently to the west to about the level of the western crest, but does not cross it. Near Richmond the gravel filling between the two crests is less uniform, being broken by sags and swells and some large depressions, so that it has more the appearance of a continuous morainal deposit than an outwash from either side.

Cutting across this interlobate tract is an eroded channel 20 feet or more in depth, which was probably developed at a subsequent stage as an outlet for glacial waters.

The fact that the ice-contact face of each morainal 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 the ice fronts were contemporaneous in their occupancy of the Darien and Johnstown moraines. There is here no indication of a difference in the vigor of the glaciers, though before the withdrawal from the interlobate tract the south front of the Darien glacier appears to have withdrawn from the Genoa moraine.

Along the trough between the contiguous frontal slopes of the two glaciers doubtless much water collected, and a vigorous flow set in 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 being washed out directly from the ice fronts along the Darien and Johnstown moraines.

In this interlobate tract conditions were favorable for the burial of masses of ice, and, as a consequence, abundant kettles, some of large size, occur. Two miles northwest of the village of Heart Prairie there is an especially intricate topography of abrupt winding gravel ridges and depressions, of which the angle of slope frequently exceeds 30°. Between the crests of the ridges and the bottoms of the immediately adjacent hollows reliefs of 60 to 100 feet occur.

The material exposed is mostly well rounded and ranges in size from coarse sand to cobblestones 8 to 12 inches in diameter. Some larger stones occur. The gravel deposit is usually covered with a coating of clay, except on the steeper crests and slopes, where it outcrops through the thin soil. Two wells in the higher parts of this tract are said to reach the rock at depths of 255 and 236 feet. The material penetrated by the wells is principally sand and gravel, with occasional layers of blue clay. In places hard blue clay is reached below the assorted material.

OUTWASH FROM THE DARIEN AND JOHNSTOWN TERMINAL MORAINES.

While the Delavan and Green Bay ice fronts occupied the outer terminal moraines, very extensive bordering deposits of stratified drift were formed. The distribution of these deposits is shown on Pl. IV, and the relations of these deposits to the pre-Glacial Rock and Troy valleys will be seen by reference to Pl. II. That the discharge of glacial waters at this stage was large in volume and vigorous in its flow is shown by the extent and character of these deposits of gravel and sand. The more sluggish waters of the closing stages 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 areas are to be found in this region.

The amount of filling in these pre-Glacial valleys is very considerable. The plain or terrace which forms the surface of this deposit has an elevation of 900 feet above the sea at the front of the moraine north of Janesville. Here there must be at least 450 feet of filling. The terrace declines southward, so that at the State line, 16 miles away, it has lowered 100 to 120 feet, and here there is probably at least 300 to 350 feet of filling.

Big Foot Prairie, at the front of the moraine near Walworth, has an elevation of 1,000 feet above the sea. If the projection of Troy Valley is correct there must be at least 500 feet of filling here outside the moraine.

Where till or "hardpan" occurs below the sand and gravel, this till 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 during the stage under discussion and how much belongs to an earlier stage, even where deep wells penetrate the deposit. There was undoubtedly an earlier glacial filling and probably considerable inter-Glacial erosion. Of 140 wells on the outwash plains, concerning which information was obtained, 114 penetrated only sand and gravel below the superficial coating of clay. Numerous other wells penetrated beds of clay or "hardpan," especially in the lower part of the section.

The tributary of the pre-Glacial Rock Valley south of the moraine, in eastern Rock County, shallows rapidly to the eastward, so that over the divide southeast of the village of Johnstown Center there is but 35 to 40 feet of gravel.

From the village of Richmond to a point about 4 miles southeast of the village of Darien such of the waters from the front of the Delavan lobe as did not cross the divide to the west found their way to Rock River by the valley of Turtle Creek. That the flow through this valley was vigorous is shown by the extensive deposit of coarse gravel leading into this valley, and by the like deposit extending from the foot of the rock gorge north of Clinton Junction to Rock River. That a considerable part of the gravels between this gorge and the State line were really washed through this Turtle Valley is clearly shown by the following facts: First, the surface of the deposit declines westward from the foot of the gorge; second, the gravels are coarser where the eastern contribution comes in, and thence southward, than north of this junction; and third, most of the exposures, especially in the eastern part of the deposit, show higher percentages of Niagara limestone than those north of this junction, thus indicating drift of easterly derivation.

The character of these gravels where cut by the Chicago, Milwaukee and St. Paul Railway, 2½ miles northwest of Allens Grove, is shown in Pl. VII, *B*. Between the Darien moraine and the Turtle Creek rock gorge very extensive erosion of these gravels took place during the subsequent recession of the glacier. An extensive lower plain was developed by the erosion of 20 to 30 feet, and in this lower terrace was cut, still later, the channel, about 20 feet in depth and 80 rods in width, whose bottom forms the present flood plain of Turtle Creek. A second channel cut in these gravels joins Turtle Valley from the north, so that only the highest terrace in the area west of Darien is to be correlated with the formation of the Darien moraine. Besides the present valleys of Rock River and Turtle Creek, this terrace is trenched to a limited extent by tributary ravines.

The outflow from the ice fronts must have been vigorous to have handled so much coarse material, though it is possible that floating ice may have assisted in transporting the larger stones. Within 2 to 3 miles of the Johnstown moraine a large part of the material exposed is of pebbles 3 to 6 inches in diameter. At the Chicago, Milwaukee and St. Paul Railway gravel pit, in the north part of Janesville, a large part of the pebbles reach 4 inches and not a few are 8 and 10 inches in diameter. Some stones of this size are seen 7 miles from the moraine. From the south part of Janesville to the latitude of Afton the great bulk of the material is coarse sand and gravel less than 2 inches in diameter.

From that part where the outwash from the Darien moraine comes in from the Turtle outlet southward 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.

Considering the volume of this discharge, the fact that no outwash crossed to the low areas behind either the Johnstown or the Darien moraine in the interlobate tract northeast of Richmond appears to be conclusive proof that the Green Bay Glacier and the Delavan glacial lobe withdrew simultaneously from these moraines. On the other hand, the relations of the morainal and outwash deposits south of Burlington leave little ground for doubt as to the contemporaneous occupancy of the Darien moraine and the Valparaiso moraine by the converging fronts of the Delavan lobe and the main Lake Michigan Glacier, respectively. The Johnstown, Darien, and Valparaiso moraines were thus contemporaneous in origin, while Marengo Ridge and the composite morainal belt on the east are of earlier age, probably having been deposited during an earlier advance of the Wisconsin stage.

The glacial drainage from the ice fronts in southwestern Kenosha County and southeastern Walworth County escaped by the Nippersink outlet through the Genoa moraine at Genoa Junction. From this time until the ice had almost entirely disappeared from Walworth County and southwestern Waukesha County this Nippersink outlet was an important factor in the development of the area. In this tract between the Darien and Genoa moraines the very gently undulating ground moraine tracts and those underlain by outwash gravels have not been very satisfactorily distinguished.

DEGLACIATION OF THE AREA.

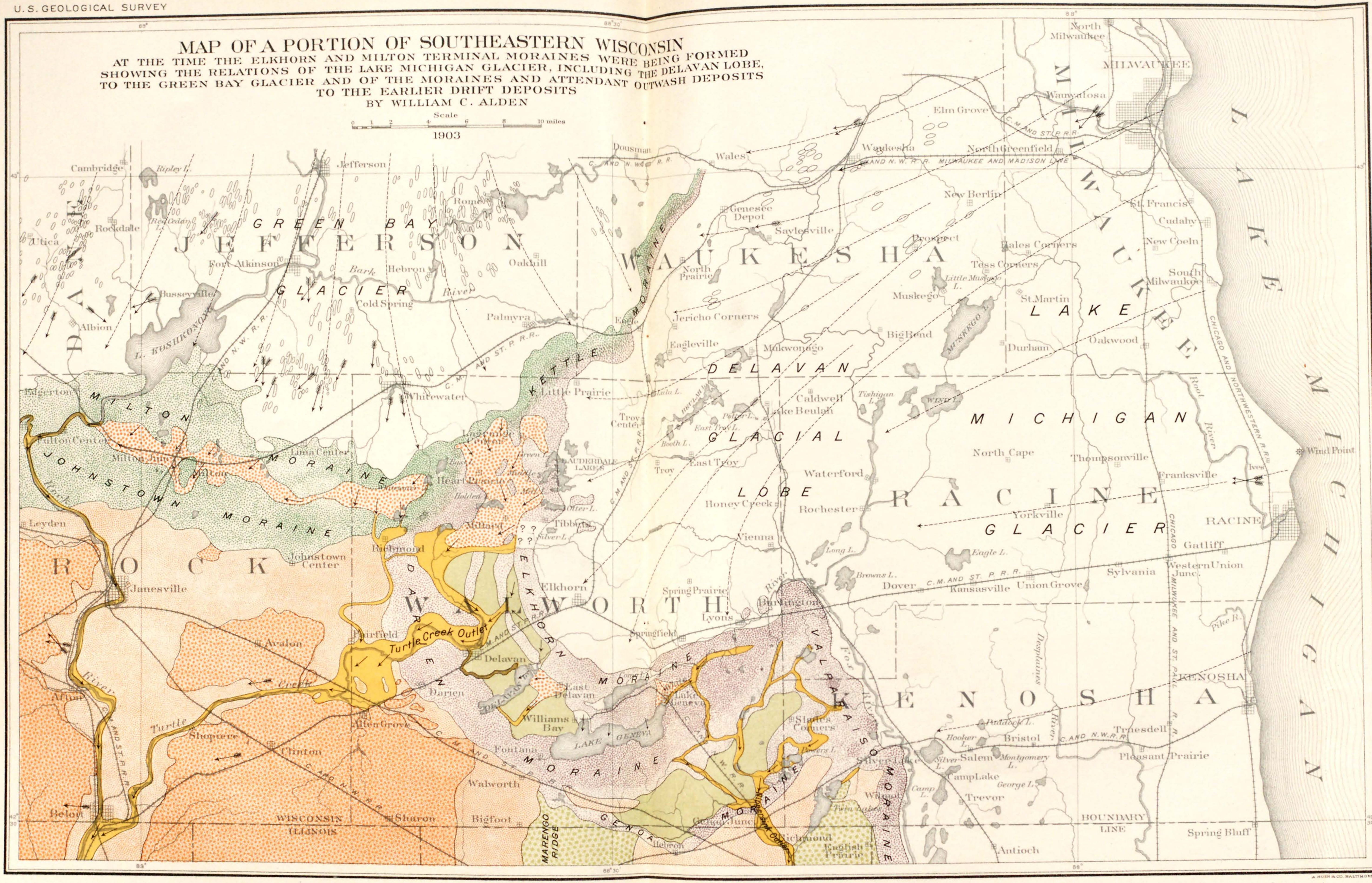
GENERAL RELATIONS.

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.

During the several stages in the deglaciation of the area the glacial waters played a very important part in the development of the phenomena of this area, and in this process the determining factors were the relations of the ice fronts of the Green Bay and Delavan glacial lobes and the successive opening of lower and still lower outlets for the glacial drainage.

ELKHORN TERMINAL MORAINE.

If the melting back of the south front of the Delavan lobe from the Genoa moraine to the Darien moraine be regarded as the first stage in the deglaciation of the area under discussion, the close of the second 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 and



LEGEND

LATE WISCONSIN DRIFT

Terraces of outwash sand and gravel associated with the formation of the Elkhorn and Milton terminal moraines

Outlets for glacial waters while the ice fronts stood at the Valparaiso, Elkhorn, and Milton moraines. Principally erosion channels cut through the outer terminal moraines and bordering gravel terraces

Terraces of outwash sand and gravel associated with the formation of the Genoa, Darien, and Johnstown terminal moraines

Interlobate morainal deposits of the Green Bay Glacier and of the Delavan lobe of the Lake Michigan Glacier

Terminal moraines of the Green Bay Glacier

Terminal moraines of the Lake Michigan Glacier, including the Delavan glacial lobe

Drumlins

Area covered by the glaciers at the time of the formation of the Elkhorn and Milton terminal moraines

Ground moraine areas of the Delavan lobe of the Lake Michigan Glacier

EARLY WISCONSIN DRIFT

Marengo Ridge and associated drift deposits

PRE-WISCONSIN DRIFT

Ground moraine

Glacial striæ

Directions of glacial movements, generalized

Directions of the flow of the glacial waters

the relations of the ice fronts are shown on Pl. V. A slight intermediate morainal belt lies east and northeast of Delavan.

The Elkhorn terminal moraine, which lies 3 or 4 miles within the Darien moraine, takes its name from the fact that it passes just west of the city of Elkhorn. This moraine varies in width from one-half mile to 2 miles, with a relief of 20 to 60 feet. Crossing the valley of Jackson Creek the moraine rises to the elevated tract where, as previously noted, it crosses what appears to be the northward extension of the 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 northern slope and crest of the ridge separating the two lake basins. A belt of similar morainal character extends eastward from the same elevated tract along the slope forming the north side of the Lake Como basin. Morainal characters are also shown by the bulky ridges running thence northeastward toward the village of Lyons. Interrupted areas of knob-and-kettle topography connect this belt with the inner part of the Darien moraine. Near the Racine County line the moraine swings northward toward Burlington. Here the knob-and-kettle topography is very strongly developed.

The west front of the Lake Michigan Glacier still occupied the morainal belt west of Fox River, and the junction of the two ice fronts formed a reentrant angle, near the apex of which stands the city of Burlington. The conditions of deposition in this interlobate angle were peculiarly favorable to the burial of masses of ice in the morainal and outwash débris, so that an area of very rough topography was produced. In the western half of this interlobate tract there is a bulky morainal deposit a mile or more in width, with a relief of 50 to 120 feet above the White River bottom on the west. In the eastern half the deposit is much weaker and is interrupted by marshy depressions. This difference in strength may be an indication that by this time the vigor of the main glacier was beginning to wane.

A marshy depression between these two parts connects with a similar valley along the south front of the Darien moraine. This channel, and two irregular breaks in the Darien moraine between Burlington and Geneva, allowed the glacial waters to escape to the Nippersink outlet at Genoa Junction.

The bulky ridge between Springfield and White River, and between Lake Geneva and Lake Como, is very largely of till. In places the morainal features have the appearance of being superposed on a preexisting drift ridge. As in the case of the ridge south of Lake Geneva, it is not improbable that the drift of these ridges may, in large part, have been deposited during an earlier glacial stage.

A well near the crest of the ridge, about 2 miles east of this exposure and 1 mile west of Geneva, was said by the driller, Mr. John Miller, of Genoa Junction, to have penetrated 317 feet of clay over the limestone. Frequent exposures along the crests and slopes of these ridges, however, show gravel. Pl. VI, *A*, shows the character of much of this morainal material. It ranges from fine gravel and coarse sand to small bowlders a foot or more in diameter, and, as elsewhere, 80 to 90 per cent of this is limestone. In some exposures the finer material is stratified and cross bedded, but usually there is little more definite bedding than can be seen in the illustration. The pebbles are generally well rounded and rarely show the striated facets seen on the stones in the till. The gravel deposits are generally coated with clay and humus, but on the more abrupt knolls and steeper slopes the soil is very thin.

The point of junction of the fronts of the Delavan lobe and Green Bay Glacier at this stage was removed to the vicinity of Lagrange Center, a position about 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 from the Delavan lobe and built up the deposit of sand and gravel underlying Heart Prairie. On the further withdrawal of the Delavan ice front that part of the area behind the Elkhorn moraine which lies between the Kettle moraine and Sugar Creek Valley was filled with outwash, which so far buried the Elkhorn morainal deposits that only the higher parts rise above the outwash plain and can be distinguished therefrom. There is thus a measure of uncertainty in the statement that the junction of the ice fronts at this stage was in the vicinity of Lagrange Center. As will be noted from the description of the conditions, however, this uncertainty is not great. Near Lagrange Center the gravel plain between the Darien and Elkhorn moraines is slightly higher than the outwash deposits to the east, and the two tracts where not separated by higher morainal deposits are separated by a narrow channel leading southward from Lagrange. This appears to have been developed by the southward flow of the water after the Delavan ice front had withdrawn somewhat to the eastward. Farther south, where the latter plain is lower, the channel cuts across it between the villages of Millard and Tibbett.

Besides their greater elevation, the higher morainal tracts are distinguished from the surrounding outwash by the undulating surfaces, by the occurrence of till, and by the occurrence of bowlders on their surfaces. Bowlders are absent from the surrounding outwash plain. The burial of the great masses of ice, whose subsequent melting formed the basins of Otter, Lauderdale, and Pleasant lakes, occurred at this time.

A. SECTION OF A KAME 1 MILE NORTH OF BURLINGTON, WIS., SHOWING THE POOR ASSORTMENT AND THE WATERWORN CHARACTER OF THE MATERIAL.

B. OUTWASH GRAVELS OVERLYING GALENA LIMESTONE AT THE HEAD OF THE TURTLE CREEK ROCK GORGE AT CARVERS ROCK, 3¼ MILES NORTHEAST OF CLINTON JUNCTION, WIS.

lakes, is bordered by an outwash apron, above which the undulating crest of the moraine rises 15 to 60 feet.

Westward to Rock River, in northeastern Rock County, the moraine is broader and less abrupt. From a narrow ridge it spreads out in a belt varying from 1 to 3 miles in width. It 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. Where the moraine crosses the pre-Glacial Rock Valley the irregular surface indicates the burial of very much ice. A notably large depression is that in which lies Clear Lake, 1½ miles northwest of Milton Junction. This has a length of nearly 2½ miles, a breadth varying from 40 rods to one-half mile, and a depth of 60 feet or more.

Immediately north of this moraine lies the basin of Lake Koshkonong, which is due to the damming of the pre-Glacial valley by the morainal deposits.

TERRACES OF OUTWASH SAND AND GRAVEL ASSOCIATED WITH THE FORMATION OF THE ELKHORN AND MILTON MORAINES.

In general, less extensive deposits of outwash material were associated with the formation of the Elkhorn and Milton moraines than border the outer terminal moraines. These deposits were limited to a large extent by the inner slopes of the outer moraines. Beyond these limits the glacial waters accomplished considerable erosion.

As has already been shown, the point of junction of the fronts of the Delavan lobe and the Green Bay Glacier was removed to the vicinity of Lagrange Center when the Elkhorn moraine was being formed, a position about 9 miles northeast of Richmond, its location at the previous stage. This position allowed the gravel-bearing water from a frontage of 3 miles on the Green Bay Glacier to be discharged into the low area behind the Darien moraine, where it commingled with that from the Delavan lobe. This outflow was unrestricted and vigorous, so that the intermorainal area received a filling of sand and gravel, which extends as far south as the valley occupied by the heads of Sugar and Turtle creeks, a distance of 6 to 7 miles from the Milton moraine. As in the other outwash aprons, the sand and gravel is generally coated with a few feet of clay and prairie loam. On this terrace stands the village of Heart Prairie.

At the front of the Milton moraine this terrace has an elevation of 980 feet above sea level. The higher parts of the narrow, broken, ridge-like crest of the moraine rise 40 to 60 feet above it. From the elevation of 980 feet at the moraine the terrace declines to an elevation of 910 to 920 feet at Turtle Creek Valley. Excepting two slightly elevated tracts of drift deposited by the Delavan glacial lobe which are surrounded by outwash material, and the depression occupied by Holden Lake, in which a great mass of ice must have been buried, this plain is nearly as flat as a floor, the uniformity being broken only by occasional slight sags.

The disposition of the deposit indicates that the outwash was principally from the Green Bay Glacier. The percentages of Niagara limestone, shown in Table F (p. 93), 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 more or less mixing probably occurred in the discharge from the trough between the contiguous ice fronts north of Lagrange Center, even if there was but little outwash from the Elkhorn moraine itself.

Of 17 wells on this terrace and the adjacent moraines, concerning which information was obtained, 5 were reported as reaching limestone at depths ranging from 200 to 235 feet. The deposits penetrated by three of the deeper wells were stated by the owners to be as follows:

Log of George MacDougal well in SW. ¼ sec. 29, Lagrange Township.

	Feet.
Clay	3 to 5
Coarse gravel	70
Sand	125
Limestone at depth of 200 feet.	

Log of J. W. Duncan well in SW. ¼ sec. 33, Lagrange Township.

	Feet.
Drift, probably gravel	65
Clay	80
Quicksand	?
Clay	40 to 50
Sand	?
Hard bluish limestone	12
Depth	247

Log of William Sherman well in SE. ¼ sec. 5, Sugar Creek Township.

	Feet.
Clay	Few
Coarse gravel	45 to 50
Sand	50
Hardpan	20
Sand and gravel	100
Depth	222

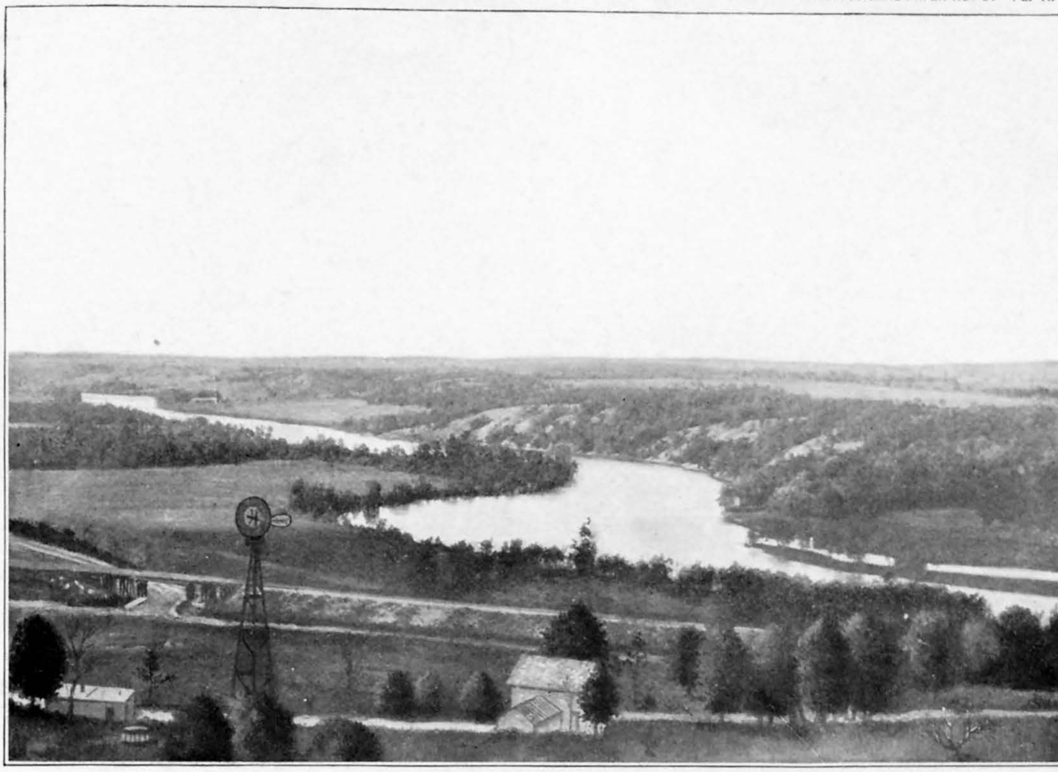
Two or three wells about 1½ miles northeast of the village of Heart Prairie penetrated about 130 feet, mostly of "hardpan." This is probably till deposited by the Delavan lobe and subsequently buried by outwash material. Most of the wells are in gravel and sand. Besides such material as was washed out from the front of the Delavan glacial lobe at this stage and mingled with that from the Green Bay Glacier in forming this deposit, a certain amount of outwash material is found bordering the Elkhorn moraine in the area west of the city of Elkhorn. A like deposit, about 2 square miles in extent, occurs east of Delavan Lake. The gravel terrace at the foot of Lake Geneva, on which the city of Geneva now stands, was probably formed at this time, and a certain amount of material may have been washed into Williams Bay at the same time, though it does not appear that the lake basin received as much filling as might be expected to have occurred.

The interval between the Milton and Johnstown moraines is occupied by an outwash gravel plain varying in width from a few rods to 2 miles (Pl. V). This is well developed in northwestern Walworth County for about 4 miles east of the county line, also to the east of the village of Milton and to the west of the village of Milton Junction. In the first of these tracts the moraine and the outwash are clearly distinct, the morainal crest rising 15 to 40 feet above the plain, which slopes gently away from the moraine. Farther west the morainal front is less distinct from the outwash. In passing from the moraine to the outwash apron in this part the surface lowers and the depressions become less frequent until they disappear almost entirely. The boundary line between the two areas is drawn more or less arbitrarily.

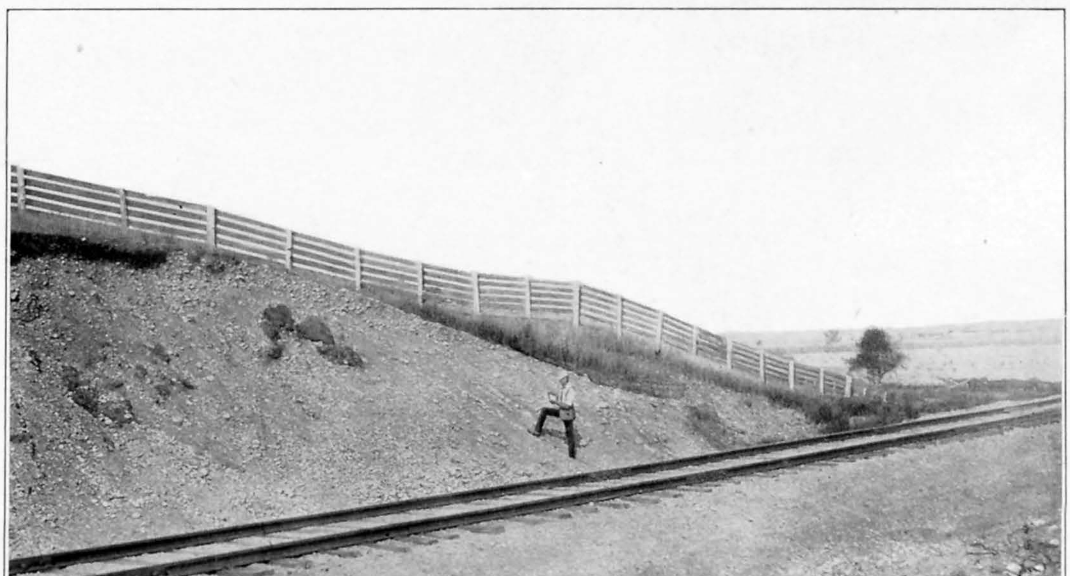
The obstruction to the westward flow of the water ponded between the Milton and Johnstown moraines in the adjacent parts of Walworth and Rock counties caused an overflow through two narrow sags near the village of Richmond. The water thus escaping reached Turtle Creek near Fairfield post-office by the channel leading southward from the village of Richmond, which is cut in the outwash plain. A similar channel across the combined Johnstown and Darien morainal deposits between Whitewater and Holden lakes, southwest of the village of Heart Prairie, allowed some of the water to escape to the low area east of the Darien moraine.

ROCK RIVER.

When the formation of the Johnstown moraine was nearly completed, it is probable that the outflow began to concentrate itself along the west side of the outwash plain and to develop the channel of the present Rock River. As the ice withdrew from the Johnstown moraine the waters ponded behind the morainal crest and found an outlet through a sag where the moraine crosses the pre-Glacial Yahara or Catfish Valley, so that while the Johnstown moraine was being formed the river headed north of the Johnstown moraine. Rock River became the outlet for all the waters discharged into the tract between the moraines from a point 4 miles southeast of Whitewater to the middle of the southern part of Dane County, a glacial frontage of more than 45 miles. The relative elevations of the various



A. THE VALLEY OF ROCK RIVER 2½ MILES NORTH OF JANESVILLE, WIS.; LOOKING NORTH.



B. VIEW AT A POINT 2½ MILES NORTHWEST OF THE VILLAGE OF ALLENS GROVE, WIS., WHERE THE CHICAGO, MILWAUKEE AND ST. PAUL RAILWAY PASSES FROM THE UPPER TO THE LOWER OUTWASH TERRACE.

sags in the crest of the Johnstown moraine show that the initial elevation of the sag where the discharge located itself was not more than 850 feet above sea level. The present elevation of the bottom of the channel at the front of the Johnstown moraine is about 750 feet above the sea. But very little of this water appears to have gone through the sag southwest of Milton Junction, though the elevation now is but 900 feet above the sea. The outwash plain opposite this sag is but very little eroded.

The character of the valley of Rock River north of Janesville is shown in Pl. VII, *A*. The moraine is dimly seen in the distance; on the right the gravel bank rises steeply 150 feet from the water's edge to the level of the outwash plain. A short distance below the bend shown in Pl. VII, *A*, after cutting through the outwash gravels, the river encountered a ridge of limestone over sandstone. The same thing occurred at two points below Janesville, as will be seen by reference to Pl. II. This was due to the fact that the new stream, instead of following the axis of the pre-Glacial valley, chose a course close to the west side of the outwash plain. In eroding its channel the stream was superimposed on salients of the rock slope at several points. Later, when the ice front withdrew from the Milton moraine and the stream extended itself across the divide between the pre-Glacial Yahara, or Catfish, and Rock River valleys, as the outlet of Lake Koshkonong, it was forced to cut its channel in rock for a mile or more above Fulton Center. It also encountered the rock at a point 2 miles east of Edgerton, near the Newville bridge.

TURTLE CREEK OUTLET.

The disposition of the glacial waters discharging into the area behind the Darien moraine at the time the Elkhorn and Milton moraines were being formed led to the development of an outlet through the Darien moraine and the erosion of a large amount of the gravels previously deposited outside.

When the front of the glacier was melted back from the crest of the Darien moraine, in the western part of Walworth County, the glacial waters, ponded between the morainal crest and the retreating ice front, found an outlet through a sag at a point west of the city of Delavan. That there was an initial sag in the crest of the moraine at this place appears from the fact that kettle holes occur in the north slope of the valley at one place down to within 40 or 50 feet of the bottom of the valley, showing that not all of the slope was due to erosion. This sag was deepened and widened by the outflow until a valley varying in width from one-half mile to 1½ miles was developed. This valley is now traversed by Turtle Creek, so that it may be conveniently referred to as the Turtle Creek outlet. From the time of the withdrawal of the ice front from the Darien moraine until the opening of Sugar Creek Valley this outlet was of great importance. From the crest of the ridge northwest of Williams Bay to the southwestern part of Waukesha County, a frontage of nearly 20 miles on the Delavan Glacier, most of the water from the melting ice went through this outlet. When the Elkhorn moraine was passed a part of this flow was diverted southward to the valleys between Lake Geneva and Burlington, and thence to the Nippersink outlet at Genoa Junction.

In addition to the flow directly from the frontage of the Delavan glacial lobe, that part of the Green Bay glacial drainage which was forming the terrace on which the village of Heart Prairie stands escaped to this outlet after depositing its load. The interlobate drainage from the two glaciers for an undetermined distance to the northeast also made a large contribution until the Green Bay front withdrew from the interlobate moraine. It is possible that even after this withdrawal a certain amount of water from this glacier, ponded between the retreating ice front and the moraine, found egress eastward across the morainal crest through some of the numerous sags, and joined the flow to the Turtle outlet.

After passing the Darien moraine by this outlet the waters found their way across the bordering outwash plain, and, as at the time when the Darien moraine was being formed, followed the present course of Turtle Creek through the rock gorge northeast of Clinton Junction and thence to Rock River.

For about 2 miles, where Turtle Creek cuts through the pre-Wisconsin drift area in eastern Rock County, the present valley is constricted. In this part the stream is bordered by a flood plain 20 to 40 rods in width, from which the side slopes rise to heights of 80 to 100 feet, the lower 60 or 70 feet of which is cut in Galena limestone. On the north side the rock is exposed in vertical bluffs. The south side is less abrupt. At the east and west ends of this gorge the limestone is overlain with outwash gravels (Pl. VI, *B*). At the east end these gravels reach a level 60 to 65 feet above the present stream. It is probable that this rock gorge marks the position of a col at the head of the broad pre-Glacial valley which opens out to the westward from its foot. This col was filled, up to the level of the higher terrace, with gravels washed out from the Darien moraine.

The vigorous outflow from the Turtle Creek outlet after the withdrawal of the ice front from the Darien moraine excavated much of these gravels, and subsequent erosion brought the valley bottom to its present position. It was reported to the writer that piling for the bridge near Winegar's quarry, north of Clinton Junction, was driven 18 feet in the valley bottom without striking rock. This report was not verified, but, if it is correct, it indicates that considerable filling remains in the bottom of the gorge, and that the rock cut can not be correlated with the development of the Turtle Creek outlet through the Darien moraine.

East of the head of this rock gorge three distinct stages may be traced in the development of the topography now seen. At the first the upper terrace or main gravel plain was formed, as previously described. North of Turtle Creek this has been but little modified by subsequent erosion. South of the creek, to the border of the older drift area, only remnants of these high-level gravels remain. One of these, a terrace varying in width from one-half to 1 mile, borders the moraine front. Parts of this terrace retain the original elevation, but more or less erosion has occurred. Except for these remnants, over an area of nearly 8 square miles, lying mostly south of the creek, these gravels have been removed to a depth of 20 to 50 feet, forming a gently undulating plain that distance below the level of the upper terrace north of the creek. This erosion appears to have been accomplished between the time of the withdrawal of the ice front from the Darien moraine and its subsequent retreat from the Elkhorn moraine. A glimpse of the relations of the upper and lower terraces may be had in Pl. VII, *B*. This view was taken in eastern Rock County, where the Chicago, Milwaukee and St. Paul Railway passes from one terrace to the other.

The top of the cut in the left foreground marks the level of the upper terrace. From this the surface drops down 30 to 40 feet to the right, in a steep erosion slope, to the lower terrace, which is seen in the right background.

The lower terrace continues northeastward 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 of 940 feet about 1 mile north of the city of Delavan, where it stands 40 feet above the neighboring flood plain of the creek. This is a rise of 60 to 70 feet in 8 or 9 miles from the points shown in Pl. VII, *B*. The surface appears to have been developed by a current that 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. From here it was deflected sharply to the northwest, 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. As the valley north of Delavan deepened, the outflow from the Elkhorn moraine deepened its course, so that, instead of finding a continuance of this lower terrace from the east side of Turtle Creek Valley to the front of the Elkhorn moraine, we find a broad valley heading in the break in the slight intermediate morainal belt northeast of Delavan, through which the Elkhorn waters found egress.

The waters continued to come to this outlet from the north for a considerable time after the retreat of the ice front from the Elkhorn moraine, until the Sugar Creek outlet was opened. 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 the lower terrace on either hand. To the east and south of Fairfield post-office the bank rises 60 feet from the flood plain of the creek to the upper terrace.

Before the Turtle Creek outlet was fully opened there appears to have been more or less of a discharge through the narrow breaks in the crest of the Darien moraine about 1 mile southeast of the village of Richmond. This was joined by a flow from the Green Bay Glacier through two narrow sags near the same village. The stream formed by the confluence of these outflows flowed southward for 2 miles close to the morainal front, where it eroded a channel 40 to 80 rods in width and 20 feet in depth. At the north line of the town of Darien this channel swings westward away from the morainal front. Near the east line of Rock County it turned to the south and finally joined the flow from the Turtle Creek outlet at a point one-half mile east of Fairfield post-office. The valley at this point is now 60 feet in depth.

ORIGIN OF LAKE GENEVA AND LAKE COMO.

With the retreat of the glacier to the Elkhorn moraine is to be associated the origin of Lake Geneva, one of the most beautiful of Wisconsin's many lakes. This lake, situated in southern Walworth County, is nearly 8 miles in length; its width varies from one-half mile to 2 miles, and the bottom of the trough in which it lies is 200 to 400 feet below the crests of the Elkhorn moraine on the north, the Darien moraine on the south, and the ridge, supposed to be the extension of Marengo Ridge, on the west. At the east the trough is more open, yet, instead of deepening toward the outlet, the lake gradually shallows in this direction. The lake reaches its greatest depth, 142 feet, in the western part, between Camp Collie and Cooks Camp. At the foot of the lake there is but a few feet of water. It is very evident that the basin was not produced by post-Glacial erosion.

The mode of its formation appears to be this: The earlier glacier of the Wisconsin stage, which formed Marengo Ridge, moved westward down the pre-Glacial Geneva Valley to its junction with Troy Valley. During the advance the valley afforded a line of discharge for the glacial waters, which flowed southward through Troy Valley. When the advance ceased Marengo Ridge was formed as a terminal moraine. This drift dam blocked the outlet of the valley, but where it crossed the pre-Glacial depression there was a considerable sag in its crest. Through this sag much water from the final melting of this glacier escaped, and this trenched the drift dam and kept the valley open. The tributary valley in which lies Lake Como discharged its waters into Geneva Valley by the way of Williams Bay. It is not improbable that these valleys afforded the principal outlet for the glacial waters of western Kenosha, southern Racine, and southeastern Walworth counties, until the ice front had retreated 25 to 35 miles to the eastward.

During the late Wisconsin invasion the ice of the Delavan lobe advanced southward across Geneva Valley and formed the Genoa and Darien moraines, the latter of which again blocked the outlet of Geneva Valley, at the same time leaving that part of the valley within the moraine unfilled with drift. There is a sag in the crest of the Darien moraine opposite the head of the lake, but its elevation, 1,000 feet above the sea, is so much greater than that of the Nippersink outlet at Genoa Junction that the westward discharge of the waters was not resumed on the withdrawal of the ice front to the Elkhorn moraine. The valley thus remains closed by a 280-foot dam of drift. When the Elkhorn moraine was formed the valley occupied by Lake Como was cut off by the morainal deposit between the heads of Lake Como and Williams Bay, and the last of the drift composing the bulky ridge to the east was deposited.

The south slope of the ridge north of Lake Geneva, on which the ice front rested for a time, shows considerably more erosion than does the north slope of the same ridge; this was not improbably due to the discharge of the glacial waters into the lake basin. Probably, also, more or less material was washed into Williams Bay at this time, and at the foot of the lake the gravel terrace on which the village of Geneva stands was formed. The remarkable thing, however, is that the basin did not receive more filling than it did. The ice must have continued longer in the basin than on the neighboring ridges, so that a filling of ice may have prevented any considerable filling with drift until the ice front abandoned the crest on the north. The disappearance of the ice from the White River and Como valleys left the lakes in their present conditions, excepting that the level of Lake Geneva is now maintained by an artificial dam.

ORIGIN OF DELAVAN LAKE.

It can not now be determined to what extent the pre-Glacial Troy Valley between Delavan Lake and the Sugar Creek Valley was filled by pre-Wisconsin drift. Farther to the northeast the trough was sufficiently open to bring about the development of the Delavan lobe, but in this part just north of the lake much of the great thickness of drift may be the remains of older sheets. The exposure of reddish till, like that of the older drift area, in the slopes north of the lake has raised a suspicion that the ridge there may be largely of older drift, especially as the older and later drift come into closest proximity, with but little intervening outwash, immediately to the west and southwest of the lake basin. This can not, however, be regarded as very good evidence, since the origin of the reddish coloring matter of the drift in this region was apparently the red beds of the lower part of the Niagara formation, which are found just beneath the drift in the vicinity of Lyons and Burlington, directly to the east of Delavan Lake, and the contributions of red material were to both the older and the later drift.

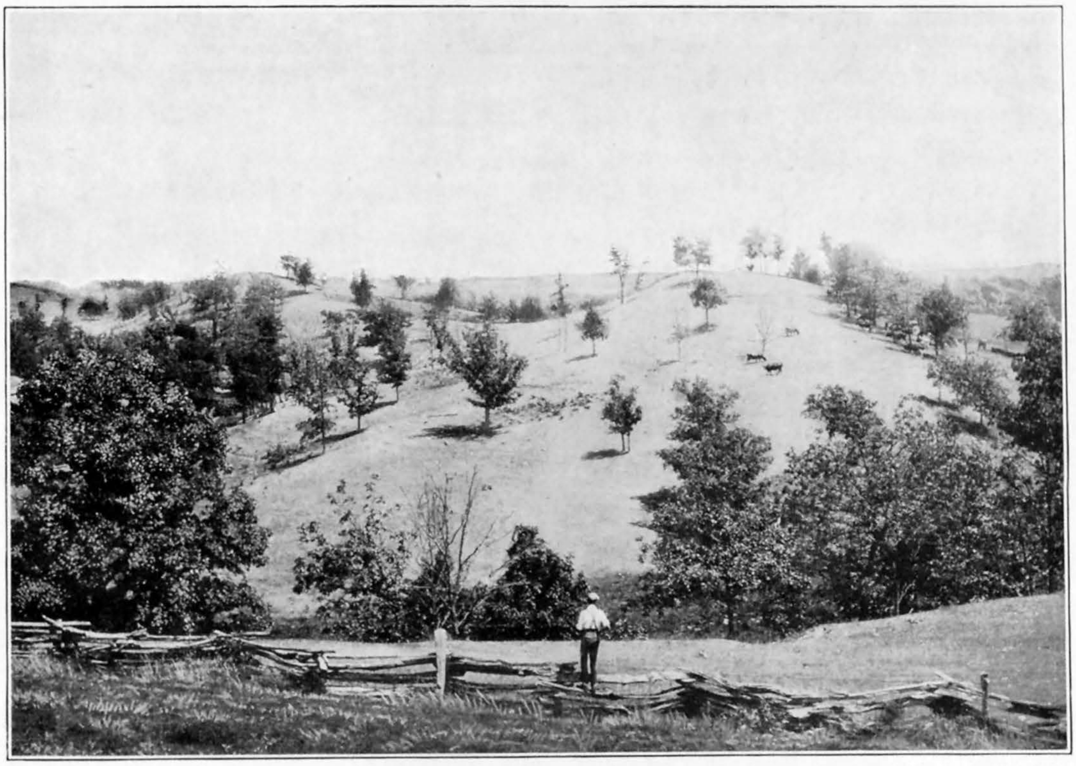
The elevated tract between this lake basin and Lake Geneva is regarded as probably due to the burial of the northwestward extension of the Marengo Ridge. During the early Wisconsin glacial invasion, while the glacial front stood at the Marengo Ridge as a terminal moraine, the water from the melting ice would be discharged into the lower area to the northwest and west, and would flow off thence to the south through Troy Valley. If the valley north of the site of the lake was largely blocked with drift, the waters would be confined to a distinct channel bordering the moraine, where they would scour out rather than make any considerable deposits. Considerable water may also have come from the northeast, near the morainal front along the line of Jackson Creek Valley, the northeastward extension of the lake basin.

When the later invasion of the Wisconsin stage took place the Delavan glacial lobe advanced over this area, deposited the Darien moraine transversely across whatever filling of older drift there may have been in Troy Valley, across the supposed northward extension of the Marengo Ridge and the intervening trough, and was melted back to the Elkhorn moraine without entirely obliterating the earlier drift features. The damming of the valley by the deposition of the Darien moraine inclosed the basin.

As in the case of Lake Geneva, a long finger of ice probably continued in the basin after the ice had disappeared from the higher areas on either side. That this really is the case there is indication in the peculiar location of the little valley just south of the lake. The position of the little valley, which was probably developed by the glacial waters when the ice front stood at the Elkhorn moraine, looks as though a mass of ice lying in the basin had held a stream halfway up the gentle slope to the southeast and forced it to cut a channel there. As the ice melted, the waters in the basin overflowed at the lowest point and there developed the present outlet.

While these hypotheses of the origin of these three lakes are not without objections, they at least afford fairly satisfactory explanations of how the basins may have been formed under the conditions afforded by the several glacial advances and retreats.

A. BALD BLUFF, A PROMINENT SALIENT OF THE INNER OR WEST FACE OF THE KETTLE RANGE, 2½ MILES SOUTHWEST OF PALMYRA, WIS., AS SEEN FROM THE SOUTHWEST



B. KAMES NEAR BASS LAKE, 5 MILES SOUTHEAST OF WHITEWATER, WIS.

INTERLOBATE KETTLE MORAINE.

Character and mode of formation.—Reference has already been made (p. 10) to the comprehensive system of moraines grouped under the terms Kettle Range or Kettle moraine. Professor Chamberlin states that the first portion of the Kettle moraine to receive systematic investigation and a specific determination of the true nature and method of its formation was that part lying between and formed by the joint action of the Green Bay and Lake Michigan glaciers, and it was this part, locally known as the Kettle Range, which gave the name to the whole system. This portion, referred to in one place[a] as the "Kettle Range proper," Professor Chamberlin recognized as belonging to a distinct type of moraines, for which he proposed the name Intermediate or Interlobate moraines,[b] from which is taken the designation "interlobate Kettle moraine," used in this paper for that portion of the moraine lying between the two glaciers. Professor Chamberlin pointed out the fact that while such moraines, lying in such a singular way between two adjacent glacial lobes, have some likeness to medial moraines, they are not such in any proper sense.

"The true medial moraine consists of superficial matter borne passively on the surface of the glacier, having been formed by the junction of lateral moraines in the union and coalesence 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."

Parts of the interlobate Kettle moraine have already been discussed. This moraine is, however, of so composite a character that it may be well, before proceeding further with the discussion of the deglaciation of the area, to consider as a whole that part of the moraine which lies within this area.

The effect of the longer continuance of the Green Bay Glacier at the interlobate Kettle moraine north of the vicinity of Bass Lake after the ice front on the east had withdrawn somewhat was to give to this moraine, to a large extent, the characteristics of an ordinary terminal moraine of the Green Bay Glacier, though the beginning of the deposition in all its parts was probably as a true interlobate moraine. From the vicinity of Richmond northeastward into Waukesha County the Kettle moraine is continuous, but its course is more or less zigzag, shifting from northeast to east in two places. These shifts are believed to be due to the relations of the two ice fronts during the successive

[a] Chamberlin, T. C., Preliminary paper on the terminal moraine of the second glacial epoch: Third Ann. Rept. U. S. Geol. Survey, 1882, p. 321.

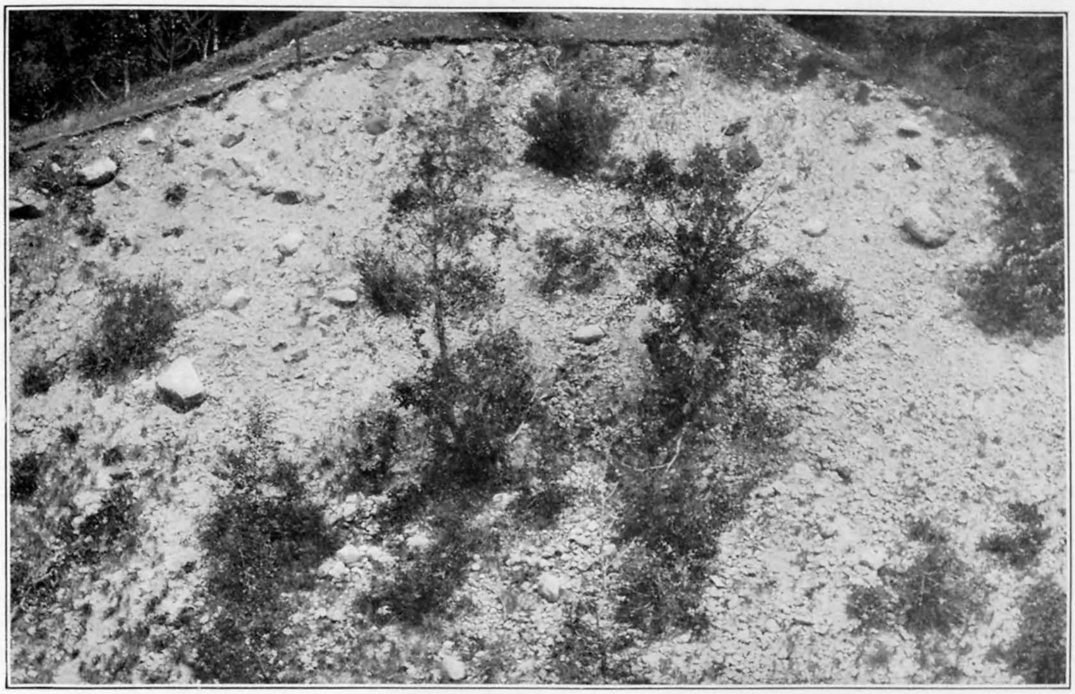
[b] Geol. Wisconsin, vol. 1., p. 276.

stages of the retreat. This moraine, as it is seen to-day, was probably developed by stages from southwest to northeast. At the first stage the Darien and Johnstown moraines for a distance of 7 miles northeast of the village of Richmond were combined into a continuous interlobate deposit, whose constituent parts are, however, more or less readily discernible. This portion, which has already been discussed, is really the only portion within this area which was completed as an interlobate moraine. The two glaciers appear to have abandoned this portion of the moraine simultaneously.

During the second stage the next 3½ miles, between a point north of Bass Lake and Lagrange Center, was completed as a part of the Milton terminal moraine of the Green Bay Glacier. This part of the moraine has a more easterly trend and is bordered on the south by the outwash plain on which stands the village of Heart Prairie. The point of junction of the two ice fronts at this stage was near the village of Lagrange Center. From this angle the main crest of the moraine, which is on the Green Bay side of the deposit, runs north 2 miles to Bald Bluff, a prominent salient (Pl. VIII, *A*), and thence northeastward 3 miles to the vicinity of the village of Palmyra. On the east and southeast of the Green Bay crest the deposit spreads out in a broad belt with pitted topography, resulting from the combination of the Milton morainal deposits with those of the Elkhorn moraine and more or less outwash material into an interlobate deposit like that extending northeastward from the vicinity of Richmond.

Many large depressions occur in this interlobate area to the west and to the northwest of the village of Lagrange Center. Beginning about 1 mile northeast of this place and extending thence nearly 1½ miles northward is an irregular, elongated depression which in its deepest part is 80 feet in depth. This has no outlet, the gravel slopes are abrupt, and the bottom is broken by knobs, ridges, and kettle holes. At two places the east front of the Green Bay crest drops abruptly 80 to 90 feet to the bottoms of narrow depressions, from which abrupt slopes rise 60 to 90 feet to what appears to be an outwash plain beyond. Numerous depressions of less depth are similarly situated. Over several square miles the area is very much broken by depressions, though here and there occur bits of flat plain topography.

The moraine on the west side of this area is strongly developed, with a ridged crest rising 20 to 80 feet above the interlobate deposits, but on the east the morainal and outwash deposits are not readily distinguished. From these relations it appears that, as the frontal slope of the Delavan lobe was melted back, the vigorous outwash from the opposing glacier buried much of the marginal ice of the Delavan lobe, from which resulted the remarkably broken character of this interlobate deposit.



A. PARTIAL SECTION OF THE KETTLE RANGE AT THE ABANDONED RAILWAY CUT AT TREE BLUFF, 4 MILES SOUTHEAST OF WHITEWATER, WIS., SHOWING THE NARROW CREST AND THE COARSENESS AND LACK OF ASSORTMENT OF THE MATERIAL.

B. LAKE CLIFF AT RACINE, WIS.

In southern Jefferson County, near Palmyra, the moraine again swings toward the east, which course it maintains to the vicinity of the village of Eagle, in southwestern Waukesha County. Here the morainal crest is marked by a series of more or less parallel gravel ridges, which alternately coalesce and diverge, giving rise to a complex topography. The frequent depressions in the bordering outwash deposits indicate that much of the marginal ice of the Delavan lobe was buried by the outwash between the two ice fronts. From the village of Eagle to a point about 5 miles north, the moraine lies partly close to and partly upon the crest of the low Niagara escarpment. Here it has a breadth of one-half to 1 mile. On the west is a low marshy tract underlain by the Cincinnati shale. The combined relief of the escarpment and the moraine varies from 100 to 200 feet. Of this relief, about 100 feet is due to the morainal deposits. From the crest the east slope drops down to an outwash terrace 20 to 40 feet below. This terrace, which, for the most part, is nearly flat, varies in width from 80 rods to 1½ miles. It declines eastward to an abrupt slope, where the surface drops down 20 to 40 feet to a second terrace.

Farther north the Green Bay Glacier overrode the Niagara escarpment and pushed some distance down the gentle east slope. Here the west front of the moraine has a relief of 80 to 100 feet. The outwash plain 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 again to a width of 1 mile.

From the relations in the vicinity of Eagle it appears probable that the Delavan and Green Bay ice fronts were still closely opposed as far south as the north end of the upper outwash terrace when the terrace was being formed. Farther south the glacial margins diverged slightly and the broad interlobate morainal belt divided into two narrower moraines, with a gravel terrace between them. At the succeeding stage the eastern moraine, which was probably weak, and much of the intervening gravel terrace were cut away by erosion.

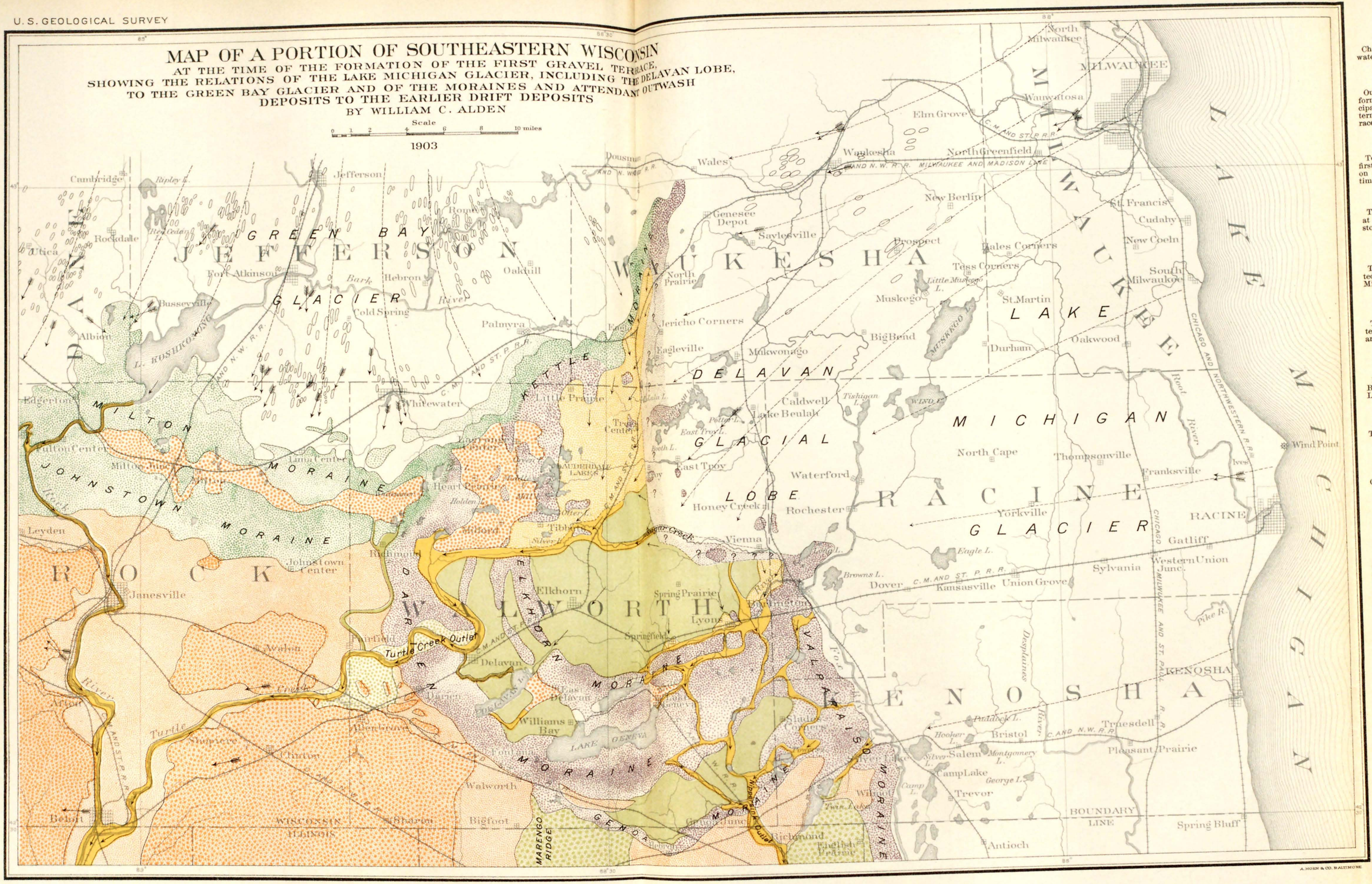
Structure of the interlobate Kettle moraine.—The interlobate Kettle moraine is one of the unique features of this area. It is, as a whole, a bulky ridge, bordered on the east by the outwash deposits already described. The surface of this ridge is marked by a knob-and-kettle topography which varies greatly in detail from place to place. At one place there may be a series of gravel ridges not unlike railroad embankments, arranged nearly parallel to each other and to the trend of the moraine. Traced longitudinally for a short distance, these ridges become winding, inclosing deep irregular depressions, with side slopes often as steep as 30° to 35°, or they may break into more or less distinct conical knobs, irregularly distributed and interset with equally 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 variation in the heights of the knobs and ridges and in the depths of the hollows at many places, combine to form a perfect wilderness of humps and hollows.

On one side 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 there may be small inclosed basins 20 to 300 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 there is usually a gradual change from the topography of the moraine to that of the bordering outwash terrace.

The composition of this moraine, as shown by the numerous exposures and by the records of wells within the morainal belt, is very largely of coarse gravel. One of the best exposures is that afforded by the abandoned railroad cut 4 miles southeast of Whitewater. The northwest or inner face of the moraine at this place has a relief of 140 to 180 feet and an angle of slope of 30° to 35° at the exposure shown in Pl. IX, *A*, which shows the narrow crest of the abrupt morainal ridge and the upper half of the 60 to 70 foot section. There is little or no evidence of assortment and stratification. The material is mostly coarse gravel and bowlders, but with this is considerable buff clay. There is very much coarse material, many of the blocks containing 5 to 10 cubic feet of rock. The gravel is well waterworn, but much of the larger material shows comparatively little wear. The greater part both of the coarse gravels and of the larger blocks is from the Galena and Trenton limestones. A few rods northwest of the point where this view was taken an exposure in the northwest slope shows similar coarse material, below which is coarse sand showing undisturbed strata dipping toward the southeast.

A 50-foot section is afforded by the road cut through the morainal crest 1 mile southeast of Palmyra. Here the gravels, which range in size from a fraction of an inch to 8 inches in diameter, are generally well rounded. In the upper part of the section the gravels are stratified; lower down the structure was obscured when seen. The stratified gravels run laterally into very stony till.

A third partial section of the moraine is that afforded by the gravel pit of the Chicago, Milwaukee and St. Paul Railway 1 mile west of the village of Eagle. This section when visited was 20 to 30 feet in height and about 40 rods long. The material ranges from clean waterworn gravel an inch in diameter to bowlders 2 feet in diameter. The longest diameters of the majority of the stones are between 2 and 8 inches. There is so little of clay or of cementation that the gravels slide down readily through the full height of the section when excavated, so that whatever stratification is present is obscured in the exposure.



LEGEND

LATE WISCONSIN DRIFT

Channels abandoned as outlets of glacial waters

Outlets of glacial waters at the time of the formation of the first gravel terrace. Principally erosion channels cut through the outer terminal moraines and bordering gravel terraces

Terraces of outwash sand and gravel, the first of a series bordering the Kettle moraine on the east and others formed at the same time

Terrace formed by erosion by glacial waters at the time the front of the Delavan lobe stood at the Elkhorn moraine

Terraces of outwash sand and gravel associated with the formation of the Elkhorn and Milton terminal moraines

Terraces of outwash sand and gravel associated with the formation of the Genoa, Darien, and Johnstown terminal moraines

Interlobate morainal deposits of the Green Bay Glacier and of the Delavan lobe of the Lake Michigan Glacier

Terminal moraines of the Green Bay Glacier

Terminal moraines of the Lake Michigan Glacier, including the Delavan glacial lobe

Drumlins

Area covered by the glaciers at the time of the formation of the first gravel terrace. The exact position of the south front of the Green Bay Glacier at this time is in doubt

Ground moraine areas of the Delavan lobe of the Lake Michigan Glacier

EARLY WISCONSIN DRIFT

Marengo Ridge and associated drift deposits

PRE-WISCONSIN DRIFT

Ground moraine

Glacial striæ

Directions of glacial movements, generalized

Directions of the flow of the glacial waters

FORMATION OF THE FIRST GRAVEL TERRACE, ON WHICH STAND THE VILLAGES OF EAGLE AND LITTLE PRAIRIE.

The stages of the glacial retreat after the withdrawal of the ice fronts from the Elkhorn and Milton moraines were marked by a complicated series of phenomena not lending themselves readily to positive correlation. The correlation here presented, however, affords a fairly satisfactory explanation of the different features.

Northeastward from southeastern Jefferson County (Pl. X) the front of the Green Bay Glacier was still crowded against the west face of the interlobate Kettle moraine, though farther south it may have begun to withdraw from the Milton moraine. Some slight morainal deposits lying just north and west of the inner margin of the Milton moraine in northwestern Walworth County and northeastern Rock County probably mark the beginning of the withdrawal from this moraine, though the exact time of their formation is not evident from the relations.

On the east the Delavan ice front continued to retreat, so that a widening interlobate angle formed in the vicinity of the village of Little Prairie and extended northeastward into Waukesha County, to a point 5 miles north from the village of Eagle. Beyond this point the two ice margins were still closely opposed, while the upper terrace which borders the interlobate Kettle moraine in the vicinity of Eagle was being formed by the outwash.

In northern Walworth County, where the front of the Delavan lobe lay across Troy Valley, the morainal deposits are so largely buried in outwash material that no continuous moraine can be traced. About 2 miles northwest of the village of East Troy (Pl. X) there is an undulating area, about 1 square mile in extent, whose bowlder-strewn surface rises 80 feet above the general level of the surrounding plain. It is possible that this and some similar smaller elevations may belong to this moraine. Over the elevated tract south of Troy Valley there are occasional groups of gravel knolls, but there is no well-defined moraine. The retreat of the ice front across this area was evidently so continuous that no moraine was formed. The junction of the Delavan ice front with that of the main Lake Michigan Glacier at this stage was somewhere between Rochester and Burlington, probably not far north of the latter place.

From Lauderdale Lake 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 Delavan glacial lobe by morainal and outwash deposits while the Elkhorn moraine and the first terrace at Eagle were being formed and during the immediately following stages of the retreat. The character of the topography thus produced is shown on Pl. XI, which is reproduced from the Eagle and Whitewater sheets of the Topographic Atlas of the United States.

The largest and most notable of these 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 can not be due to fluvial erosion is shown by the exceedingly abrupt and irregular marginal slopes and by the inequalities in depth where not now occupied by marsh deposits (Pl. XII). The lakelets, ponds, and marshes occupying these depressions in many cases lie 50 to 80 feet below the surrounding plain. The marginal gravel slopes are very abrupt and are often made exceedingly irregular 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, and some of the crests are so narrow that two teams could not pass upon them, while the slopes drop down at angles of 30° to 35°.

The character of the deposits is shown by the following wells on this first terrace:

Log of W. S. Watson's well in the village of Little Prairie.

	Feet.
Gravel	40
Hardpan	40
Sand	40
Hardpan	2
Gravel	4
Depth	126

Log of Robert Cross's well, 2 or 3 miles south of the village of Little Prairie.

	Feet.
Stony clay	16
Gravel and sand	125
Stony clay	?
Gravel	?
Depth	254

Log of McKee Brothers' well, 5 miles west of the village of East Troy.[a]

	Feet.
Blue clay	66
Sand	160
Hardpan	4
Layers of hardpan each 3 or 4 feet thick alternating with layers of sand	171
Rock	3½
Depth	404½

[a] Information furnished by W. L. Thorne, a well driller of Whitewater, Wis.

Henry Gannett, Chief Topographer.
Jno. H. Renshawe, Geographer in charge.
Triangulation by the U. S. Coast and Geodetic and Lake Surveys.
Topography by Van. H. Manning Jr.
Surveyed in 1889.

TOPOGRAPHIC MAP OF PORTIONS OF WALWORTH, WAUKESHA, AND JEFFERSON COUNTIES, WISCONSIN

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.

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 Glacier, nor what part may have been deposited during earlier stages of glaciation.

The disposition of the glacial waters at this stage was of considerable importance. The drainage from that part of the Green Bay Glacier lying southwest of the village of Palmyra probably escaped to Rock River by way of the low tracts bordering the inner margin of the Milton moraine (Pl. X); that from the Green Bay front east and northeast of Palmyra, from 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 Jackson Creek Valley through the Elkhorn moraine, south of the city of Elkhorn. South of 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 débouchures of the valleys by the water coming from the elevated area to the north. Probably also about this time the gravels underlying Gardners Prairie, northwest of Burlington, were deposited as an outwash deposit.

Two miles west of the village of Vienna a small valley heads in a sag in the south slope of Sugar Creek Valley, and leads thence southward to the White River bottom northeast of the village of Lyons. This valley is eroded to a depth of 40 to 100 feet, yet there is now scarcely any area tributary to it except its own immediate slopes, so that it contains no stream and shows very little evidence of recent erosion, such as marks the valley one-half mile west. This little valley was evidently not due to post-Glacial erosion. It was probably developed by the glacial waters at this time.

ORIGIN OF SUGAR CREEK VALLEY.

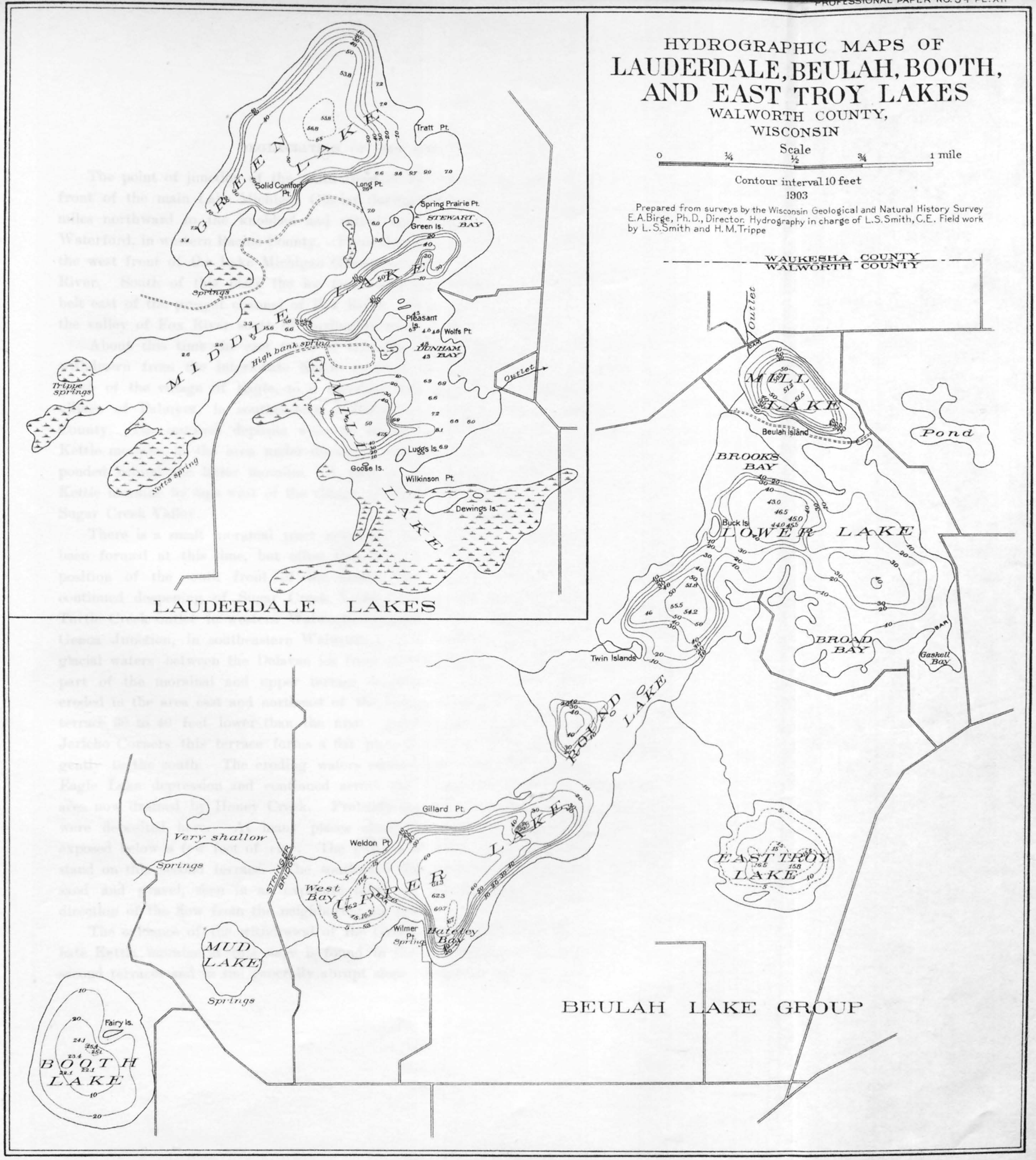
The peculiar relationships of Sugar Creek Valley, which cuts through the elevated ground-moraine area northeast of Elkhorn (Pl. X), probably can be explained by the drainage conditions of this stage. The relationships are these: In the first place, the amount of erosion required for its excavation is not equaled, in the area of the later drift examined by the writer, in any valley having so limited an area of tributary drainage. Its flat, marshy bottom varies in width from 40 rods to nearly one-third of a mile, and through this bottom meanders a rivulet so small as to be out of all proportion to the capacious valley. 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 the low marshy area, 900 to 920 feet above the sea, to a low area northwest of Burlington having an elevation of 760 to 800 feet. In doing so it cut through an elevated track, which, in its highest part on the immediate crests of the valley slopes, reaches an elevation of 1,040 to 1,060 feet above the sea. 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 the ordinary conditions of erosion.

There is no evidence of an underlying pre-Glacial valley which might have caused a sag in the drift surface of such depth as to cause the drainage from the west to follow this line in preference to Turtle Creek on the west or Honey Creek on the north. In fact, the rock is exposed at one point in the valley bottom, and wells to the north and the south indicate that the elevation of the rock there is about the same as in the valley exposure. We must therefore look for special conditions for the explanation of this valley.

These conditions were probably furnished by the ice front retreating toward the northeast from the Elkhorn moraine. It is not improbable that there was an initial sag in the drift surface. This sag would be deepened by water flowing westward to Turtle Creek from the retreating ice front, so long as the glacier lay across the line of the valley. The valley thus extended eastward and trenched the highest part of the area nearly to the level of Turtle Creek Valley, northwest of Elkhorn. When the ice front 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. This diversion accomplished, the abundant flow further deepened Sugar Creek Valley, and the Turtle outlet was abandoned.

FORMATION OF A SECOND GRAVEL TERRACE, IN SOUTHWESTERN WAUKESHA COUNTY AND NORTHEASTERN WALWORTH COUNTY.

The diversion of the glacial drainage from the Turtle outlet through the Sugar Creek Valley to the Nippersink outlet marks the next stage in the deglaciation of the area (Pl. XIII). The continued melting of the Delavan glacial lobe carried the margin back to the moraine lying in southwestern Waukesha County, just west of the villages of Genesee and Genesee Depot. The ice lay across the elevated ground moraine tracts between the village of North Prairie and the village of Mukwonago, and continued in Troy Valley, while the south margin of the lobe was being melted back to the line of gravel hills lying 2 miles east of the village of East Troy.


HYDROGRAPHIC MAPS OF
LAUDERDALE, BEULAH, BOOTH, AND EAST TROY LAKES
WALWORTH COUNTY, WISCONSIN
Scale
0 ¼ ½ ¾ 1 mile
Contour interval 10 feet
1903
Prepared from surveys by the Wisconsin Geological and Natural History Survey E.A.Birge, Ph.D., Director. Hydrography in charge of L.S.Smith, C.E. Field work by L.S.Smith and H.M.Trippe
WAUKESHA COUNTY
WALWORTH COUNTY
LAUDERDALE LAKES
GREEN LAKE
MIDDLE LAKE
MUD LAKE
Tratt Pt.
Solid Comfort Pt.
Long Pt.
Spring Prairie Pt.
STEWART BAY
Green Is.
Springs
Pleasant Is.
Wolfs Pt.
DENHAM BAY
High bank spring
Outlet
Trippe springs
Notts spring
Luggs Is.
Goose Is.
Wilkinson Pt.
Dewings Is.
BEULAH LAKE GROUP
MILL LAKE
Beulah Island
Pond
BROOKS BAY
Buck Is.
LOWER LAKE
BROAD BAY
Gaskell Bay
Twin Islands
ROUND LAKE
Gillard Pt.
Very shallow
Weldon Pt.
Springs
STRINGER BRIDGE
West Bay
UPPER LAKE
Wilmer Pt.
Spring
Bateley Bay
MUD LAKE
Springs
EAST TROY LAKE
Fairy Is.
BOOTH LAKE

The point of junction of the south front of the Delavan lobe with the west front of the main Lake Michigan Glacier during this stage was moved 6 or 7 miles northward to the knobbed and pitted tract northwest of the village of Waterford, in western Racine County. From this angle southward to Burlington the west front of the Lake Michigan Glacier occupied the moraine west of Fox River. South of this place the ice front may have retreated to the morainal belt east of the present channel of Fox River. It is not certain, however, that the valley of Fox River south of Burlington was yet cleared of ice.

About this time the east front of the Green Bay Glacier appears to have withdrawn from the interlobate Kettle moraine for an undetermined distance north of the village of Eagle, to a morainal belt running northward from the village of Palmyra, in southeastern Jefferson County and western Waukesha County. The outwash deposits were no longer made east of the interlobate Kettle moraine in the area under discussion, but were laid down in the waters ponded behind the latter moraine. A part of this ponded water crossed the Kettle moraine by sags west of the village of Eagle, and joined the flow through Sugar Creek Valley.

There is a small morainal tract northeast of Whitewater which may have been formed at this time, but other than this there is nothing to indicate the position of the south front of the Green Bay Glacier. The opening and continued deepening of Sugar Creek Valley, causing the abandonment of the Turtle Creek outlet in western Walworth County for the Nippersink outlet at Genoa Junction, in southeastern Walworth County, accelerated the flow of the glacial waters between the Delavan ice front and the Kettle moraine, so that a part of the morainal and upper terrace deposits of the previous stage were eroded in the area east and northeast of the village of Eagle, forming a second terrace 30 to 40 feet lower than the first. Between the villages of Eagle and Jericho Corners this terrace forms a flat plain 2 miles in width which declines gently to the south. The eroding waters crossed the buried ice masses in the Eagle Lake depression and continued across the terrace southward to the low area now drained by Honey Creek. Probably the gravels eroded farther north were deposited here. At many places along the railroad these gravels are exposed below a few feet of clay. The villages of Troy Center and East Troy stand on this second terrace. The southward dip of the cross-bedding of the sand and gravel, seen in an exposure north of the latter place, shows the direction of the flow from the neighboring ice front.

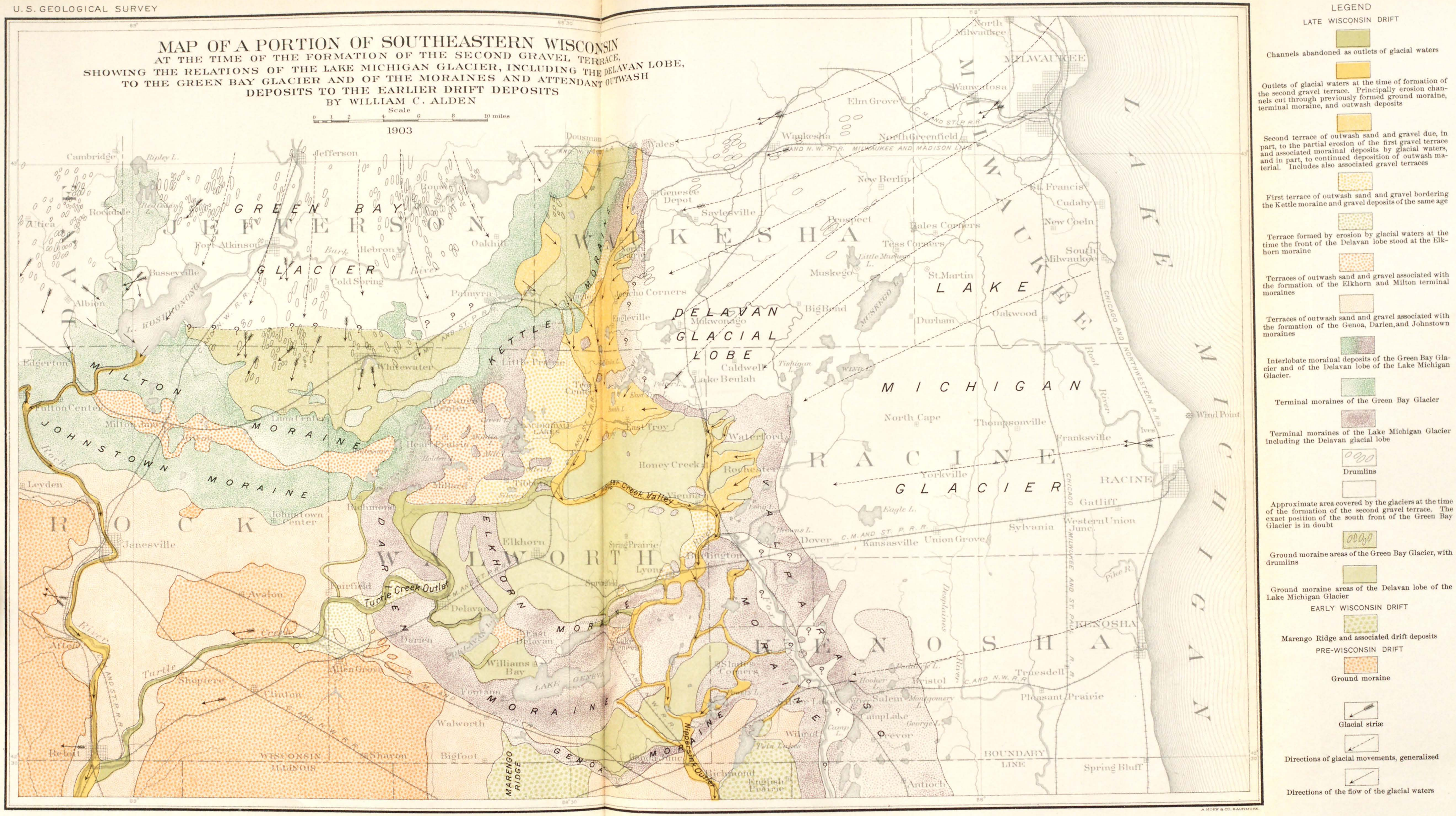
The evidence of the withdrawal of the Green Bay Glacier from the interlobate Kettle moraine at this stage is found in the distinctness of the upper and second terraces and in the generally abrupt slope separating the two. So far as noted, there is no evidence that outwash from the Green Bay Glacier crossed this upper terrace and marginal slope to the lower terrace, whence it is inferred that the outwash from the west had ceased and that the Green Bay Glacier had abandoned the moraine.

FORMATION OF A THIRD GRAVEL TERRACE, IN SOUTHWESTERN WAUKESHA COUNTY AND NORTHEASTERN WALWORTH COUNTY.

By the time the second terrace had been completed and the ice front had been melted back to its next line of morainal deposits the lobation of the west margin of the Lake Michigan Glacier had become very slight. This was all that remained of the Delavan lobe (Pl. XIV). The ice front still stood at the moraine in the vicinity of the villages of Genesee and Genesee Depot, but farther south it had retreated to the vicinity of Mukwonago, leaving great masses of ice buried in the gravels in Troy Valley. The great depressions resulting from the subsequent melting of these ice masses have already been described (Pl. XI). In the vicinity of Mukwonago the ice front lay to the north and east of the village, along the morainal deposits which block the converging tributaries of the pre-Glacial Troy Valley. South of this the morainal deposits of this stage are found between the villages of Lake Beulah and Caldwell Prairie. Northwest of the village of Waterford they connect with the Valparaiso moraine of the Lake Michigan Glacier. For 2 miles below the village of Rochester the ice may have continued at the moraine west of the river, but farther south Fox River Valley must certainly have been clear by this time.

This stage was thus marked by the opening of the lowest outlet for the glacial drainage yet available, that by way of Honey Creek to Burlington and thence by Fox River to Illinois River. When fully cut down, the elevation of this channel at the west line of Racine County, about 3 miles north of the village of Honey Creek, was about 800 feet above the sea, while that of the head of Sugar Creek Valley north of Elkhorn is at an elevation of 860 to 870 feet. At the State line the channel of Fox River is about 740 feet above the sea, while the Nippersink outlet at Genoa Junction is about 830 feet. The greater fall by way of Honey Creek and Fox River thus gave it a great advantage over the outlet by way of Sugar Creek Valley and the Nippersink outlet, so that this latter outlet in its turn was abandoned. This opening of a lower outlet for the glacial drainage resulted in a further acceleration of the flow, and, as a consequence, the second terrace east of the village of Eagle was itself in part eroded and a third and still lower terrace was formed.

The distinction between the second and third terraces is most plainly marked in the area southwest of the village of Jericho Corners, in southwestern Waukesha


MAP OF A PORTION OF SOUTHEASTERN WISCONSIN
AT THE TIME OF THE FORMATION OF THE SECOND GRAVEL TERRACE,
SHOWING THE RELATIONS OF THE LAKE MICHIGAN GLACIER, INCLUDING THE DELAVAN LOBE,
TO THE GREEN BAY GLACIER AND OF THE MORAINES AND ATTENDANT OUTWASH
DEPOSITS TO THE EARLIER DRIFT DEPOSITS
BY WILLIAM C. ALDEN
Scale
0 1 2 4 6 8 10 miles
1903
LEGEND
LATE WISCONSIN DRIFT
Channels abandoned as outlets of glacial waters
Outlets of glacial waters at the time of formation of the second gravel terrace. Principally erosion channels cut through previously formed ground moraine, terminal moraine, and outwash deposits
Second terrace of outwash sand and gravel due, in part, to the partial erosion of the first gravel terrace and associated morainal deposits by glacial waters, and in part, to continued deposition of outwash material. Includes also associated gravel terraces
First terrace of outwash sand and gravel bordering the Kettle moraine and gravel deposits of the same age
Terrace formed by erosion by glacial waters at the time the front of the Delavan lobe stood at the Elkhorn moraine
Terraces of outwash sand and gravel associated with the formation of the Elkhorn and Milton terminal moraines
Terraces of outwash sand and gravel associated with the formation of the Genoa, Darien, and Johnstown moraines
Interlobate morainal deposits of the Green Bay Glacier and of the Delavan lobe of the Lake Michigan Glacier.
Terminal moraines of the Green Bay Glacier
Terminal moraines of the Lake Michigan Glacier including the Delavan glacial lobe
Drumlins
Approximate area covered by the glaciers at the time of the formation of the second gravel terrace. The exact position of the south front of the Green Bay Glacier is in doubt
Ground moraine areas of the Green Bay Glacier, with drumlins
Ground moraine areas of the Delavan lobe of the Lake Michigan Glacier
EARLY WISCONSIN DRIFT
Marengo Ridge and associated drift deposits
PRE-WISCONSIN DRIFT
Ground moraine
Glacial striæ
Directions of glacial movements, generalized
Directions of the flow of the glacial waters
GREEN BAY GLACIER
DELAVAN GLACIAL LOBE
LAKE MICHIGAN GLACIER
LAKE MICHIGAN
JEFFERSON
WAUKESHA
MILWAUKEE
RACINE
KENOSHA
WALWORTH
ROCK
KETTLE MORAINE
MILTON MORAINE
JOHNSTOWN MORAINE
ELKHORN MORAINE
DARIEN MORAINE
VALPARAISO MORAINE
GENOA MORAINE
MARENGO RIDGE
Turtle Creek Outlet
Sugar Creek Valley
Nippersink Outlet
WISCONSIN
ILLINOIS
BOUNDARY LINE
A. HOEN & CO. BALTIMORE

County, where, for nearly 2 miles, a short, abrupt slope of 15 to 20 feet separates the plain of the second terrace from a like lower plain. At Jericho Corners and at several points between this and the village of North Prairie the gravels were so far removed as to expose the underlying rock. A remnant of the second terrace is seen in the flat-topped ridge extending northward from a point three-fourths of a mile north of Jericho Corners.

The morainal and outwash deposits in the vicinity of Mukwonago completely closed the branches of Troy Valley to further southwestward drainage, and gravel and sand were deposited around and over the ice masses remaining in the Troy basin, thus completing their burial. In general, the elevation of these outwash deposits decreases toward the head of Honey Creek outlet at the west line of Racine County. In the western part of Racine County sand and gravel were washed out through the sags leading between the ridges of the ground-moraine till to the valley of Honey Creek. Sand and gravel deposits also border Fox River more or less continuously from Burlington to the State line.

HEBRON MORAINE.

The stages of retreat of the front of the Green Bay Glacier can no longer be surely correlated with those of the Lake Michigan Glacier within the area under discussion. It is not improbable, however, that about the time of the formation of the third terrace east of the village of Eagle the front of the Green Bay Glacier stood at a weak morainal belt in southern Jefferson County, which may be traced, with some discontinuity, from a point 3 miles northeast of the village of Rome, where it enters this area from the northeast, in a broad curve southwestward, then westward, then northwestward past the village of Hebron and Fort Atkinson to the vicinity of Ripley Lake in western Jefferson County, and thence northwestward beyond the area under discussion (Pl. XIV). This morainal belt may be conveniently referred to as the Hebron moraine from its relation to the village mentioned.

In some parts this moraine is rather strongly developed and is bordered by terraces of sand and gravel. At other points the morainal deposits scarcely obscure the drumloidal topography which they overlie. The relations of the morainal belt extending northward near the Jefferson-Dane county line from the west end of Lake Koshkonong have not yet been fully determined. The further retreat of the Green Bay ice front carried it beyond the limits of the area under discussion.[a]

[a] Further examination of the area has resulted in tracing a very weak but distinct moraine from the vicinity of Rome westward through the Jefferson County farm, southwest of Jefferson, and thence northwestward beyond the limits of the area under discussion. This moraine marks the position of a halt of the retreating ice front about 2 miles north of the Hebron moraine.

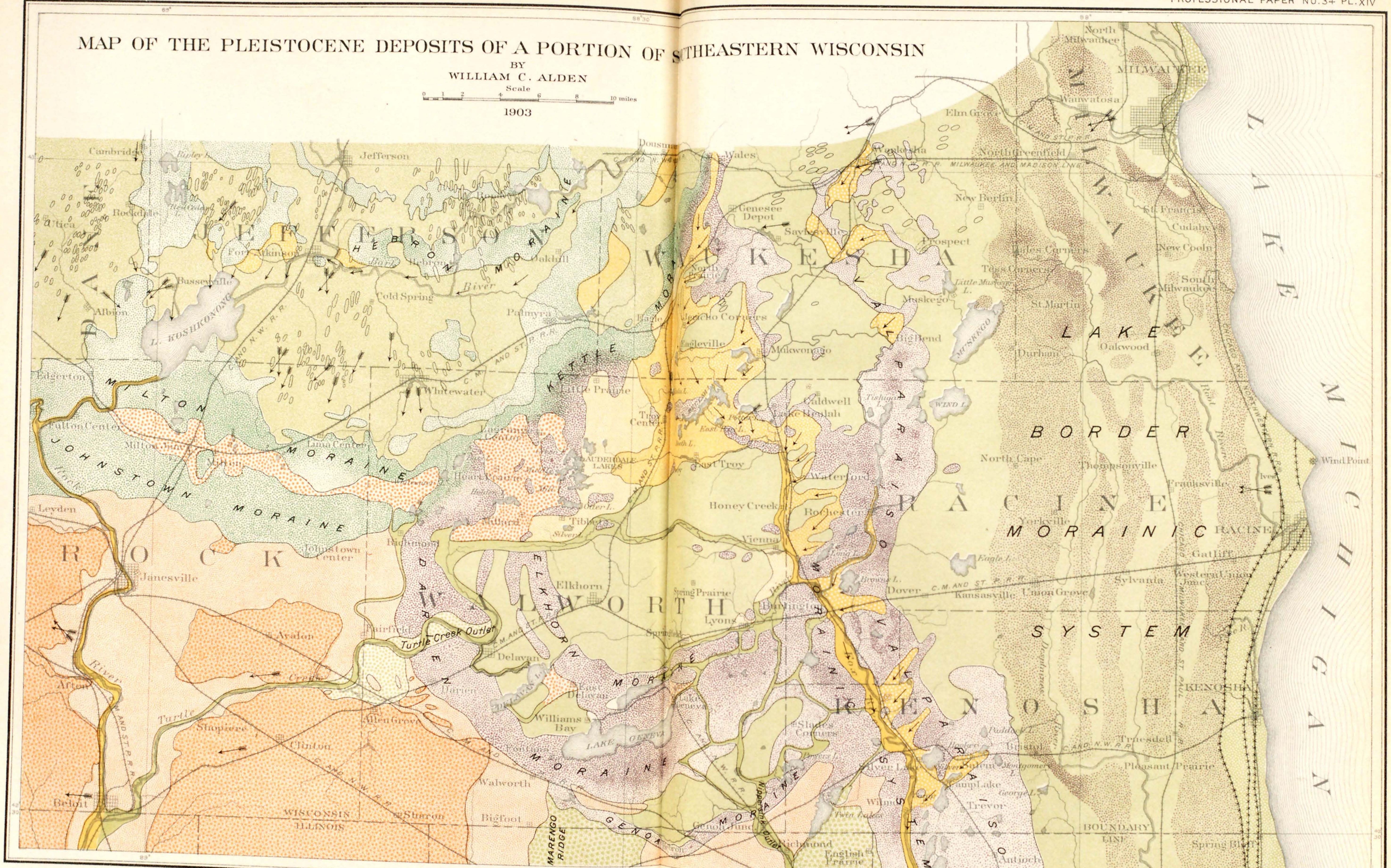
Just how rapidly the morainal and rock barriers below Lake Koshkonong were cut down is not known, but it is probable that for some time the glacial waters were ponded between the Milton moraine and the retreating ice front of the Green Bay Glacier, forming an extensive lake which covered the lower areas of southern Jefferson County, northeastern Rock County, and northwestern Walworth County. Lake Koshkonong and the extensive marsh areas of the region are the remnants of this glacial lake. In trenching the drift and rock barriers near Fulton Center the stream had to cut through about 35 feet of drift and 50 feet of limestone and sandstone. Farther south, where the rock was not encountered, the amount of drift eroded was much greater. In time, if the artificial dams in Rock River are not maintained, Lake Koshkonong and the marshes will disappear as the river further deepens its channel. Laminated clays which were deposited in the glacial lake are exposed in the clay pits at the brick yards at Fort Atkinson and Jefferson.

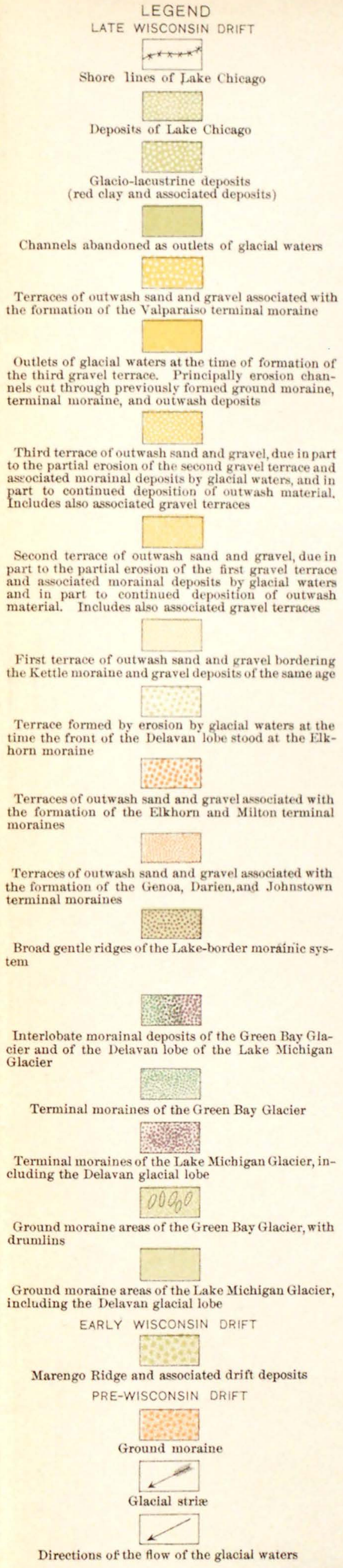
VALPARAISO TERMINAL MORAINIC SYSTEM.

The next stage in the deglaciation of the area was marked by the entire disappearance of the Delavan lobe and by the opening of the valley of Fox River between Waukesha and Burlington. So gradual was the withdrawal of the main west front of the Lake Michigan Glacier that it was yet occupying the morainal belt bordering Fox River when the ice of the Delavan lobe had so far disappeared that its margin occupied the northward continuation of the same moraine (Pl. XIV).

The Valparaiso morainic system, where it enters Kenosha County, Wis., from Lake County, Ill., has a breadth of nearly 10 miles. The western part of the belt along Fox River is marked by discontinuous groups of kames forming bulky ridges, whose surfaces are pitted with kettle holes. These alternate with low, marshy tracts, and with nearly flat areas underlain by sand and gravel deposits. Farther east the topography is marked by broader undulations and depressions with abrupt ice-contact slopes, which are occupied by lakelets and marshes.

In the northern part of Kenosha County the morainal belt narrows and a distinct ground-moraine topography appears to the east. As far north as the vicinity of the village of Waterford, in western Racine County, there is a continuous bulky moraine, such as would be expected from so long occupancy by the front of the Lake Michigan Glacier. From this place northward to the vicinity of Waukesha, where the occupancy by the ice front was very much shorter, the morainal deposits, though spread over an area of considerable width, are very much scattered and are insufficient in amount to obscure the drumloidal ground-


MAP OF THE PLEISTOCENE DEPOSITS OF A PORTION OF SOUTHEASTERN WISCONSIN
BY
WILLIAM C. ALDEN
Scale
0 1 2 4 6 8 10 miles
1903
JEFFERSON
WAUKESHA
ROCK
WALWORTH
RACINE
KENOSHA
MILWAUKEE
LAKE MICHIGAN
LAKE BORDER MORAINIC SYSTEM
HEBRON MORAINE
KETTLE MORAINE
MILTON MORAINE
JOHNSTOWN MORAINE
DARIEN MORAINE
ELKHORN MORAINE
GENOA MORAINE
VALPARAISO SYSTEM
MARENGO RIDGE
Turtle Creek Outlet
WISCONSIN
ILLINOIS
BOUNDARY LINE
Milwaukee
Waukesha
Racine
Kenosha
Janesville
Beloit
Whitewater
Jefferson
Cambridge
Edgerton
Delavan
Elkhorn
Burlington
Lake Geneva
Wind Point
A. HOEN & CO. BALTIMORE.


LEGEND
LATE WISCONSIN DRIFT
Shore lines of Lake Chicago
Deposits of Lake Chicago
Glacio-lacustrine deposits (red clay and associated deposits)
Channels abandoned as outlets of glacial waters
Terraces of outwash sand and gravel associated with the formation of the Valparaiso terminal moraine
Outlets of glacial waters at the time of formation of the third gravel terrace. Principally erosion channels cut through previously formed ground moraine, terminal moraine, and outwash deposits
Third terrace of outwash sand and gravel, due in part to the partial erosion of the second gravel terrace and associated morainal deposits by glacial waters, and in part to continued deposition of outwash material. Includes also associated gravel terraces
Second terrace of outwash sand and gravel, due in part to the partial erosion of the first gravel terrace and associated morainal deposits by glacial waters and in part to continued deposition of outwash material. Includes also associated gravel terraces
First terrace of outwash sand and gravel bordering the Kettle moraine and gravel deposits of the same age
Terrace formed by erosion by glacial waters at the time the front of the Delavan lobe stood at the Elkhorn moraine
Terraces of outwash sand and gravel associated with the formation of the Elkhorn and Milton terminal moraines
Terraces of outwash sand and gravel associated with the formation of the Genoa, Darien, and Johnstown terminal moraines
Broad gentle ridges of the Lake-border morainic system
Interlobate morainal deposits of the Green Bay Glacier and of the Delavan lobe of the Lake Michigan Glacier
Terminal moraines of the Green Bay Glacier
Terminal moraines of the Lake Michigan Glacier, including the Delavan glacial lobe
Ground moraine areas of the Green Bay Glacier, with drumlins
Ground moraine areas of the Lake Michigan Glacier, including the Delavan glacial lobe
EARLY WISCONSIN DRIFT
Marengo Ridge and associated drift deposits
PRE-WISCONSIN DRIFT
Ground moraine
Glacial striæ
Directions of the flow of the glacial waters

moraine topography developed during the advance of the glacier.[a] Evidences of a morainal stage in this part are found in patchy areas with pitted topography, sags and swells, occasional gravel knolls, and the very great abundance of surficial bowlders.

Perhaps the most notable deposit of this stage of the retreat is the great abundance of bowlders scattered over the high region between Waukesha and the Muskego lakes. These bowlders have been very largely collected from the fields and piled in walls along the fences. In some parts of this tract there are many fields inclosed by walls of bowlders 3 feet or more in height. In a certain pasture lot about 1 mile west of Little Muskego Lake, where the bowlders appeared to be about as originally deposited, neither having been collected nor having received additions from adjacent fields, the writer counted 4,200 bowlders in less than 2 acres. It was possible to have crossed this lot by stepping from one stone to another. Of these bowlders less than 1 per cent were of other than foreign crystalline rock.

Besides the gravels bordering Fox River in Racine and Kenosha counties, there is a gravel terrace nearly 2 square miles in extent on which stand the villages of Big Bend and Chamberlain, in southeastern Waukesha County. Other like terraces occur farther north, the city of Waukesha standing on one of these.

As is shown by the previous discussion, 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 glacial lobe. 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 moraine 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 even after the Green Bay Glacier had begun its retreat. The Valparaiso moraine in Illinois, as described by Mr. Leverett,[b] the Genoa and Darien moraines, as described in this paper, and that part of the Kettle moraine which in this paper is designated the Johnstown moraine of the Green Bay Glacier, thus mark the limit of the last glacial advance of the late Wisconsin stage of glaciation in southern Wisconsin and northeastern Illinois. The deposits of the early Wisconsin glaciers in southern Wisconsin were almost entirely overridden by the shifted ice lobes of the later invasion.

[a] Further examination of the area has resulted in grouping these scattered morainal deposits into two or three fairly distinct belts crossing the towns of Waukesha and Vernon from southeast to northwest. These are branches of the Valparaiso moraine, and their disposition indicates more of a lobation of the west margin of the glacier at this stage than would appear from the above description and from Pl. XIV.

[b] The Illinois glacial lobe: Mon. U. S. Geol. Survey, vol. 38, 1899, p. 399 et seq.

LAKE-BORDER MORAINIC SYSTEM.

As already noted, the Valparaiso morainic system is bordered on the east by a distinctively ground-moraine tract. East of this, in Milwaukee County, eastern Waukesha County, and the eastern halves of Racine and Kenosha counties, there is a series of broad, gentle ridges of drift which nearly parallel the shore of Lake Michigan. Mr. Leverett in his studies[a] found these same ridges continuing southward into Cook County, Ill., between the Valparaiso moraine and the lake shore. Similarly located ridges of drift were found in northwestern Indiana and southern Michigan, which were thought to belong to the same series. This system of ridges, which appears to mark further stages in the retreat of the Lake Michigan Glacier, has been designated by Mr. Leverett the lake-border morainic system. The distribution of these ridges in the area under discussion is shown on Pl. XIV. While in a large part of this extent the ridges are clearly marked and distinctly separated, so as to give the peculiar north-south trend to the drainage lines, they are cut through at intervals by the streams, and in some places contiguous ridges are coalescent, 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.

It has been stated that when the front of the Delavan lobe reached the Valparaiso moraine in its retreat the lobe had almost disappeared. During these subsequent stages, however, there was enough lobation of the margin to give a marked westward shift to these lake-border ridges in Milwaukee County. This westward shift amounts to 6 or 7 miles, so that new ridges appear to the east, in northern Milwaukee and in Ozaukee counties, which have no correlatives at the south (Pl. III), or their southward continuations are to be found beneath the waters of Lake Michigan.

In general the topography of this lake-border belt differs but little from an ordinary ground-moraine area. Here and there groups of kettle holes pit the surface, and in some places considerable deposits of gravel occur, but for the most part the surface is marked by broad, gentle undulation. The notable feature of the tract is the disposition of the drift in broad ridges parallel to the lake shore, so that, though the general elevation decreases toward the east, the drainage reaches the lake only where the streams have cut transversely across the trend of the ridges, as in the case of Root and Pike rivers. One of the streams, Desplaines River, in fact does not enter the lake, but flows southward to Illinois River. Milwaukee River flows more than 30 miles between ridges of this lake-border system before it enters the lake at Milwaukee, though through most

[a] The Pleistocene features of the Chicago area: Bull. Chicago Acad. Sci., No. 2, 1897, pp. 42–47. The Illinois glacial lobe: Mon. U. S. Geol. Survey, vol. 38, 1899, pp. 380–412.

of this distance its course is within 3 miles of the lake, and at some points the shore is less than 1 mile distant. These ridges vary in width from 1 to 4 miles, and generally have longer east slopes and shorter west slopes, so that the elevations of the crests are successively lower on passing eastward to the lake. The crest of the west ridge stands 220 to 360 feet above Lake Michigan. The middle belt is marked by two more or less distinct crests, one of which is again subdivided.

The most sharply defined of these ridges south of Milwaukee is that lying nearest the lake shore. This ridge is continuous 25 or more miles southward, to Winnetka, Ill., where it is intersected by the lake shore. The crest of this ridge 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. The reliefs on the west sides of these ridges range from 20 to 60 feet, and on the east from 60 to 180 feet. The thicknesses of the drift penetrated by wells range from a few feet, where some buried rock ridges occur, to 300 or more feet where there are pre-Glacial valleys beneath. The bulk of the drift appears to be till, but extensive stratified beds are exposed in the lake-bluff section of the east ridge.

While the front of the Lake Michigan Glacier stood at the west ridge of the lake-border morainic system in Waukesha and Racine counties, the water from the melting ice was ponded over the low areas to the west or flowed directly to Fox River. The outflow evidently was not vigorous, as no outwash deposits have been found. Muskego and Wind lakes and the surrounding marshes are evidently the remnants of an extensive shallow lake formed at this time.

On the withdrawal of the Lake Michigan Glacier from the Valparaiso moraine in Illinois, Indiana, and Michigan a marginal lake was formed by the waters accumulating between the inner slope of the moraine and the retreating ice front. From Kenosha County southward the water discharged from the ice front, as it stood at the west ridge of the lake-border morainic system, flowed southward to this lake.

When the ice margin withdrew to the middle belt the flow of the glacial waters to Fox River ceased entirely. Thenceforward all the water from the melting glacier in the area under discussion went southward to this glacial lake by the valleys between these ridges. The final withdrawal of the ice front from the east ridge of this series allowed the expanding lake to reach southeastern Wisconsin, substituting lacustrine for glacial conditions in the eastern part of this area.

LAKE CHICAGO.

GENERAL RELATIONS.

As has already been indicated, as soon as the front of the Lake Michigan Glacier of the Wisconsin stage of glaciation had retired from the crest of the Valparaiso moraine in southwestern Michigan, northwestern Indiana, and northeastern Illinois the direct discharge of the glacial drainage into watercourses leading away from the ice front was obstructed, and the waters accumulated between the ice front and the crest of the moraine as a marginal lake. This glacial lake was initiated at the south and expanded northward with the melting of the ice. As the west margin of the glacier withdrew to the successive ridges of the lake-border morainic system, the intervening valleys became occupied by broad streams discharging southward into the glacial lake. It is even possible that the water overtopped the middle and east ridges. In the lake-border area of southeastern Wisconsin glacial and aqueous depositions were closely associated.

During these initial stages of the lake no distinct shore phenomena were developed, possibly because of the constant shifting of the water level as the barrier at the outlet was cut down, and because of the large amount of floating ice which obstructed wave action. The accumulating waters found an outlet near the south end of the basin, along the line of the present Desplaines River Valley, across the Valparaiso moraine southwest of Chicago, Ill. (Pl. III). Through this valley, known as the Chicago outlet, the waters found their way to Illinois and Mississippi rivers. The various phases of this glacial lake, to which Mr. Leverett has given the name "Lake Chicago," have been discussed in several publications.[a]

GLENWOOD STAGE.

The highest level at which a distinct shore line is now recognizable about the southern part of the basin is 640 to 650 feet above the sea, or 60 to 65 feet above the level of Lake Michigan. The shore line at this level has been designated the Glenwood shore line, from its strong development near the village of Glenwood, Ill., south of Chicago. Between Winnetka and Waukegan, Ill., the encroachment of the lake upon the land during the later stages has destroyed the ancient shore line, but from Waukegan northward to a point 5 miles north

[a] Andrews, Edmund, The North American lakes considered as chronometers of post-Glacial time: Trans. Chicago Acad. Sci., Chicago, 1870, pp. 1-24.

Leverett, Frank, The Pleistocene features and deposits of the Chicago area: Bull. Geol. Nat. Hist. Survey, Chicago Acad. Sci., No. 2, 1897, pp. 57 et seq.

Leverett, Frank, The Illinois glacial lobe: Mon. U. S. Geol. Survey, vol. 38, 1899, pp. 416-459.

Salisbury, R. D., and Alden, W. C., The geography of Chicago and its environs: Bull. Geog. Soc. Chicago No. 1, 1899.

Alden, W. C., Description of the Chicago district: Geologic Atlas U. S., folio 81, U. S. Geol. Survey, 1902.

of Racine, Wis., an old shore line is recognizable at a level corresponding to that of the Glenwood beach south of Winnetka, Ill. Through Racine and Kenosha counties this shore line lies between 1 and 2 miles west of the present lake shore. It is marked in places by a low cliff of till and a wave-cut terrace, but for the most part there is a well-developed ridge of beach sand and gravel lying on the gently rising surface of the till. These deposits occur mostly at levels between 50 and 60 feet above the present lake, though at some places limited deposits occur 70 to 80 feet higher than the present lake. East of this shore line there is a flat plain underlain by extensive deposits of lacustrine sands and clays.

Nowhere in Milwaukee or Ozaukee counties is this shore line now to be seen. For at least 11 miles northward from the point of intersection of the Glenwood shore line by the present lake bluff, in northeastern Racine County, the ancient beach has been destroyed by the encroachment of the lake upon the land during the subsequent stages. Farther north the relations are complicated by a deposit of red clay overlying stratified beach deposits.[a] It appears probable that these buried beach deposits are to be referred to the Glenwood stage, though this has not yet been fully demonstrated.

For the detailed discussion of the relations of the red clay deposit which borders the lake shore from Milwaukee northward and the underlying lacustrine deposits, reference should be made to the Milwaukee folio of the Geologic Atlas of the United States.[b] The correlation there presented is, in brief, as follows: It is suggested that the interstratified gravel, sand, and clay immediately overlying the till in the lower part of the lake-bluff section northward from a point about 5 miles southeast of Milwaukee harbor was deposited near the shore at the Glenwood stage of Lake Chicago, the front of the glacier having withdrawn an unknown distance to the north and east. From some unknown source there was introduced into the drift being deposited in the lake along the oscillating front of this glacier a tenacious red clay. Besides deposition directly from the melting ice front, the distribution of this clay may have been accomplished in part by floating ice. A part of it came within the zone of deposition near the shore, so as to be deposited as laminated clays interbedded with more or less material derived from the drift along the beach. It is further suggested that a readvance of the glacier occurred, crowding upon the land as far south as Milwaukee, overriding the stratified beds and leaving on them and on the till beyond their western limits the deposit of stony red clay now found bordering the lake from the vicinity of Milwaukee northward.

It has not yet been satisfactorily determined, however, whether this readvance

[a] Geol. Wisconsin, vol. 1, 1883, pp. 291-295, and vol. 2, 1877, pp. 219-230.

[b] Alden, W. C., Description of the Milwaukee district: Geologic Atlas U. S., folio — (in preparation), U. S. Geol. Survey.

of the glacier is to be correlated with the latter part of the Glenwood stage or whether the retreat of the ice front continued during this stage, reaching such a position as to allow the drawing down of the lake waters by some low outlet, to be followed by a readvance of the ice, blocking the outlet and reflooding the basin at the Calumet stage.

LOW-WATER STAGE.

The occurrence of a bed of peat beneath the deposits of the Calumet stage in the vicinity of Evanston, Ill., has led to the belief that, following the Glenwood stage, there was a time during which the waters were drawn down to a level even lower than that of the present lake, so that a part of the previously submerged area emerged.

Mr. Leverett[a] cites the deep channels in the lower courses of the streams tributary to the lake along the east shore in Michigan as also giving evidence of this emergence. He states that the soundings shown by the United States Lake Survey charts, from Pere Marquette Lake southward to Kalamazoo River, demand an emergence of at least 50 feet above the shore, even if the bottoms of the channels are but slightly filled. 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. It was not, however, satisfactorily determined whether this emergence occurred between the Glenwood and Calumet stages or between the Calumet and Toleston stages.

Certain evidence of an interval of emergence was noted by the writer in the vicinity of Milwaukee harbor. It is possible, however, that the phenomena there observed were developed after, rather than before, the Calumet stage. They are discussed in a subsequent connection. It is probable that the cause of the low-water stage was the wasting of the Lake Michigan Glacier to such an extent that an outlet was opened to the northeastward which was lower than the Chicago outlet.

CALUMET STAGE.

Following the low-water stage the lake basin was again flooded and the southwestward discharge through the Chicago outlet was resumed. This second high-water stage was probably due to the closing of the northeasterly outlet. If the deposition of the red clay north of Milwaukee occurred at this stage the closing of this outlet was due to the readvance of the Lake Michigan Glacier

[a] Op. cit., p. 441.

southward to the latitude of Milwaukee. It appears to make little essential difference in the interpretation of the phenomena of this area whether the glacial deposition of the red clay be regarded as occurring before or after the interval of emergence which preceded the Calumet stage. The evidence on this point is thus far not decisive. At whatever stage this readvance and deposition of this clay occurred, lacustrine conditions south of the latitude of Milwaukee were correlated with the glaciation north of this latitude. On the retreat of the glacier the lake again extended itself northward.

The Calumet stage of Lake Chicago received its name from Mr. Leverett because of the relations of Calumet River, in Cook County, Ill., to the shore line. During the Glenwood stage the discharge through the Chicago outlet had cut down the barrier so that at the Calumet stage there was formed a shore line which now stands 35 or 40 feet above the level of Lake Michigan. The Calumet shore line is well developed all about the south end of the lake basin. It has been cut away between Evanston and Waukegan, Ill., but, extending northward from Waukegan to a point about 4 miles north of Racine, Wis., there is an ancient beach at the same elevation as that south of Evanston Ill. (Pl. XIV). Through Kenosha County the distance of this old shore line from the present beach varies from a few rods to nearly a mile. In Racine County, excepting where it cuts across Wind Point, the old beach deposits lie at the crest of the present lake bluff (Pl. IX, *B*). From a point 1½ miles northwest of Wind Point light-house nearly 50 miles to the north so great has been the encroachment of the lake upon the land that no trace of the old shore line remains.

POSSIBLE SECOND LOW-WATER STAGE.

Reference has already been made to the evidence of a low stage of water which Mr. Leverett[a] found at Holland, Mich. This evidence consists of an abandoned valley leading from Grand Rapids to Holland, Mich., at a depth at least 30 feet lower than the present lake level. This channel was formed subsequent to the formation of a beach which now stands upon a flat 30 to 40 feet above the lake, and prior to a lower beach which is now 25 feet above the lake. If the higher beach ridge, which is built up to 60 to 65 feet above the lake, is the Calumet beach, the emergence must have occurred between the Calumet and the Toleston stages.

Records of test borings on file in the office of the city engineer at Milwaukee show the presence of marsh deposits in the lower courses of Milwaukee and Menominee rivers at Milwaukee, extending about 50 feet below the level of

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[a] Op. cit., p. 446.

the lake. These indicate that at some stage, when the lake waters had withdrawn approximately 50 feet below their present level, the valleys were cut down to that level. A refilling of the lake basin flooded the lower parts of the valleys and caused them to be filled with marsh and lake deposits. The fluctuation of the lake level indicated by this is commensurate with that shown by the channels on the east side of the lake. Unfortunately there seems to be nothing to indicate just at what time this emergence took place. It seems probable, however, that it did not occur prior to the deposition of the red clay.

The draining off of the waters at this stage, as before, was probably due to the opening of a northern outlet, either by a depression in that region or by the withdrawal of an obstructing glacier.

TOLESTON STAGE.

An obstruction of the northeast outlet again brought about a high-water stage and a resumption of the southwestward discharge through the Chicago outlet. The cutting down of this outlet had progressed so far that, at the Toleston stage, the lake developed its shore line but 20 to 25 feet above the present level of Lake Michigan. This third shore line, which takes its name from the village of Toleston, Ind., is well developed about the south end of the lake basin. Like the Calumet shore line, it has been destroyed between Evanston and Waukegan, Ill., but is yet preserved from Waukegan to Kenosha, Wis., where it is closely followed by the line of the Chicago and Northwestern Railway. From the State line to Kenosha it lies one-half to three-fourths of a mile from the present beach. North of Kenosha for nearly 60 miles it is entirely cut away except for some remnants of terraces in Milwaukee County.

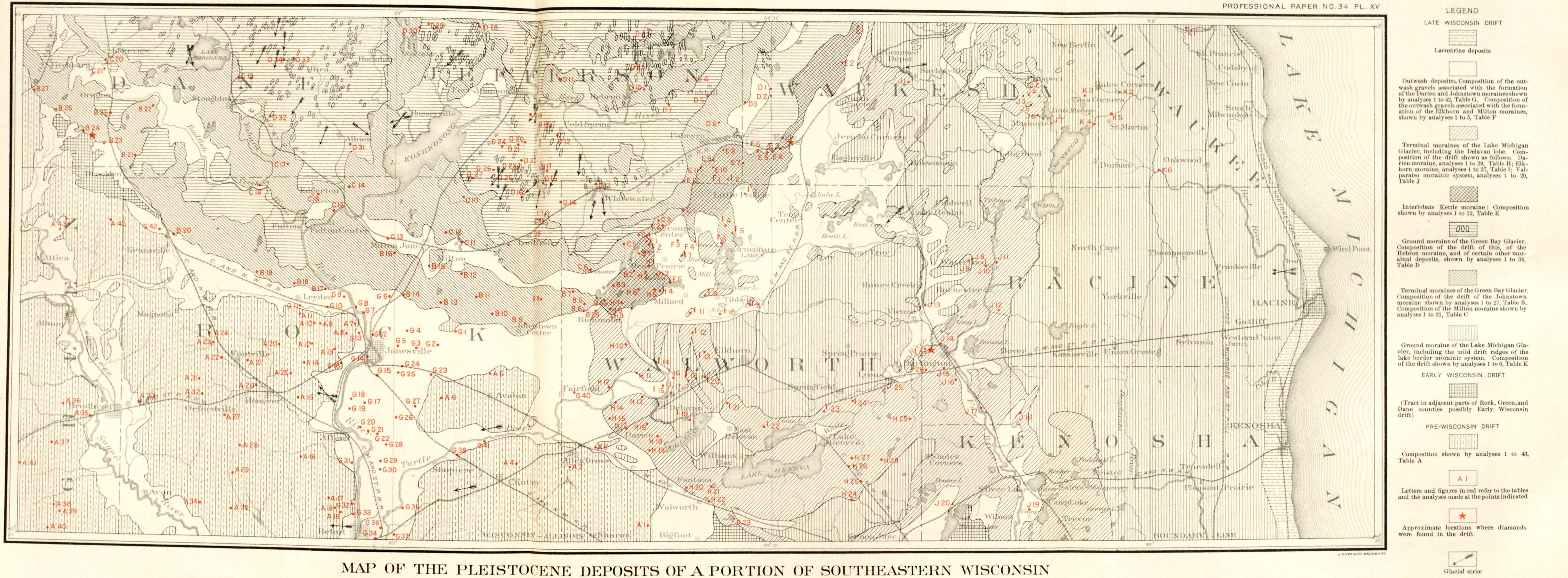
LAKE MICHIGAN.

The final opening of the Straits of Mackinac and the consequent lowering of the lake level caused the abandonment of the Chicago outlet and the initiation of the present stage of the lake. The name "Lake Michigan" is applied to the lake from the final closing of the Chicago outlet to the present.

LITHOLOGICAL COMPOSITION OF THE DRIFT.

GENERAL STATEMENT.

In order to obtain a somewhat definite knowledge of the lithological composition of the glacial drift of southeastern Wisconsin, as a basis for deductions concerning the derivation, transportation, and deposition of the material composing the various glacial features, a large number of analyses of the drift of this region have been made. The data for these have been gathered during



MAP OF THE PLEISTOCENE DEPOSITS OF A PORTION OF SOUTHEASTERN WISCONSIN

SHOWING DISTRIBUTION OF ANALYSES OF DRIFT RECORDED IN TABLES A TO K

BY WILLIAM C. ALDEN

Scale

0 1 2 4 6 8 10 miles

1903

several years of study, and embrace an area somewhat larger than that covered by the preceding discussion. It has been thought best, however, to put the results of this study into permanent form; and since most of these data have to do with the phenomena treated at length in the preceding discussion, it may be as well to incorporate the whole in this paper.

The data presented are the results of the examination of about 47,400 rock specimens collected at 266 places distributed over an area of about 2,940 square miles, embraced between parallels 42° 30′ and 43° north latitude and meridians 87° 45′ and 89° 30′ west longitude. This area, in southeastern Wisconsin, includes the whole of the counties of Racine, Kenosha, Walworth, and Rock; the southern parts of Milwaukee, Waukesha, and Jefferson counties; the southeastern part of Dane County, and the eastern part of Green County.

This area includes considerable tracts of pre-Wisconsin drift, the southern part of the area covered by the Green Bay Glacier, the area covered by the Delavan glacial lobe, and a part of the main Lake Michigan Glacier, and the attendant outwash deposits. The results of the analyses are shown in the accompanying tables, A–K, and the distribution of the places at which the analyses were made is shown on Pl. XV. Of these estimates, 43 were made in the pre-Wisconsin drift area, 42 in the outwash deposits bordering the Darien and Johnstown moraines, 27 in the Johnstown terminal moraine, 21 in the Milton terminal moraine, 12 in the interlobate Kettle moraine, 34 in the ground-moraine tract of the Green Bay Glacier, including the Hebron terminal moraine, and certain other morainal deposits, 29 in the Darien terminal moraine, 27 in the Elkhorn terminal moraine, 20 in the Valparaiso terminal moraine, 5 in the outwash deposit between the Darien and Elkhorn moraines, and 6 in the lake-border moraines of the Lake Michigan Glacier.

METHOD OF ANALYSIS.

In making these analyses, one to several hundred pebbles were taken indiscriminately from the drift at each of the places indicated; these were sorted with reference to the rock formations from which they were derived, and the percentages noted. Owing to the infrequent occurrence of fossils, the determinations were necessarily based on lithological characters. The characters of the several rock formations of the area are generally so distinctive as to be readily recognized by one familiar with them. There are, however, gradations from one type to another, so that discriminations can not always be made; thus, at best, the determinations can be considered as but rough approximations of the truth. Undoubtedly the judgment of different persons would differ considerably as to the identification of the rock specimens at any given locality. There would be very little variance, however, in their judgment as to what was of local derivation and what was foreign to the area.

Further, the soft shales of the Cincinnati group, whose contribution was principally to the rock-flour matrix of the till, are entirely neglected in these estimates, and the friable sandstones of the St. Peter and Potsdam groups are probably not fully represented in the coarser material of the drift. Notwithstanding these limitations, the value of the results obtained is far from being vitiated. The remarkable agreement between the results obtained on the distribution of the local material and what would be expected from a priori consideration of the conditions of deposition, indicates more than a mere coincidence; and the still more remarkable agreement between the relative proportions of local and foreign material shown by the different tables seems to indicate that, taken in a large way, the results of the analyses must be very near a true exposition of the composition of the drift of the area. In consequence of the conditions of the determinations care must be taken not to press too far inferences based on mere local differences.

LOCAL AND FOREIGN MATERIAL IN THE DRIFT.

In considering the drift of any given part of this area, we may regard as foreign constituents all those rock fragments for which no parent formations are known within the limits of eastern Wisconsin in the path of the glacial movement which reached or crossed the tract in question. Thus, as will be seen by reference to Pl. I, in the area traversed by the Lake Michigan Glacier we may regard as foreign all the crystalline rocks, quartzites, and sandstones, and all the limestones and shales which can be identified as from formations below the Trenton group or above the Devonian. Excepting the area of the Delavan glacier lobe, the Trenton and Galena limestones and the Cincinnati shale, if they occurred, would also be excluded from the local material. As a matter of fact, the identifications by the writer have warranted only the classification of the crystalline rocks, the sandstones, and the quartzites as foreign material in the drift of the Lake Michigan Glacier.

In the drift of that part of the area traversed by the Green Bay Glacier lying within the district under discussion, all the Paleozoic material, limestones, sandstones, and shales, from the Potsdam to the Niagara, inclusive, may be of local derivation. The knobs of the Huronian quartzite in northwestern Jefferson County and southeastern Dodge County, in what is known as the Waterloo area, contributed much quartzite material, from which it is difficult to discriminate quartzite material which may be from more distant points, so that in the Green Bay drift only the crystalline rocks are regarded as certainly of foreign derivation. Certain crystalline knobs occur in eastern Wisconsin, but not in the track of the ice reaching the south end of the lobe.

So also in the pre-Wisconsin drift areas, only the crystalline rock material is regarded as surely of foreign derivation, inasmuch as a large part of the quartzite material there found has been regarded as derived from the Waterloo quartzite knobs.

If now we consider the 266 analyses presented in the accompanying tables with reference to the percentages of local and foreign material in the drift of the area under discussion, it is seen that the foreign material ranges from 3 to 32 per cent at the exposures examined, with the exception of one point where 50 per cent of foreign material was found. The average percentage of foreign material shown by all the analyses made is 12.93. That the variations are within narrow limits is shown by the following:

Résumé of analyses of drift materials.

Number of analyses.	Percentage of foreign material.
230	20
23	20 to 25
11	25 to 30
1	32
1	50
266	[a] 12.93

[a] Average.

If we consider the drift deposited by the several glaciers with reference to the percentages of local and foreign material, omitting the averages for the outwash deposits and the interlobate Kettle moraine, in all of which there was a mixture of drift from the Green Bay Glacier and the Delavan glacial lobe, the following results are obtained:

Amount of foreign material in drifts.

	Percentage of foreign material.
Pre-Wisconsin drift	11.55
Drift of Green Bay Glacier	10.73
Drift of Lake Michigan Glacier, including the Delavan glacial lobe	15.55

Taking the averages of the terminal moraines, we find the following percentages:

Amount of foreign material from Green Bay Glacier.

	Percentage of foreign material.
Johnstown moraine	10.03
Milton moraine	10.53
Average of 48 analyses	10.248

Amount of foreign material from Lake Michigan Glacier.

	Percentage of foreign material.
Darien moraine	15.74
Elkhorn moraine	17.46
Valparaiso moraine	13.259
Average of 76 analyses	15.698

If we omit the sandstones and quartzites from the foreign material of the Lake Michigan drift, taking only the crystalline rocks, as in the Green Bay drift, the difference stands as follows:

Comparative amounts of foreign crystalline material from Green Bay and Lake Michigan glaciers.

	Percentage of foreign crystalline rocks.
Green Bay Glacier moraines	10.248
Lake Michigan Glacier moraines	14.904

There appears to be no very notable difference between the ground moraine and the terminal moraines in the percentage of foreign material, as shown by the following:

Comparative amounts of foreign material from ground and terminal moraines.

	Percentage of foreign material.
Green Bay ground moraine	11.42
Johnstown terminal moraine	10.03
Milton terminal moraine	10.53

In the interlobate Kettle moraine, the Heart Prairie outwash deposits bordering both the Elkhorn and the Milton moraines, and the outwash deposits bordering both the Darien and the Johnstown moraines, in all of which the drift of the Green Bay and Lake Michigan glaciers is commingled, the drift is of an intermediate character, as shown by the following:

Amounts of foreign material in commingled drift from Green Bay and Lake Michigan glaciers

	Percentage of foreign material.
Interlobate Kettle moraine	15.99
Heart Prairie outwash deposit	11.71
Darien-Johnstown outwash deposit	12.78
Average of 59 analyses	13.34

A notable evidence of the thorough commingling of the local and foreign material during the transportation and deposition is found in the fact that in not one of the analyses of the material taken at random from these 266 exposures is crystalline material absent.

In considering the transportation of these erratics it should be noted that in all probability not a little of this foreign material was carried well on its way southward by the glaciers of the earlier stages, and was picked up and carried onward during the later advances. Thus, if the facts were known it might be found that a considerable part of what is here called foreign material in the later drift sheets was picked up from the earlier drift at no great distance from the place of final deposition.

ENGLACIAL AND SUBGLACIAL DRIFT.

On the final melting of a glacier the englacial and superglacial drift is left commingled with the upper part of the subglacial drift or upon its surface. It is doubtful if englacial and superglacial till can be successfully distinguished from subglacial till after deposition has taken place. Being carried higher up in the ice, it would presumably be carried farther before it was deposited, so that the englacial drift at any given place might reasonably be expected to show a higher percentage of foreign material than that which was of subglacial origin. None of the material examined for analyses was found more than 30 or 40 feet below the surface, and most of it was from surface exposures or excavations but a few feet in depth. It represents ground moraine, terminal moraine, and outwash deposits, drumlins, kames, and esker-like ridges; yet nowhere has the writer seen any evidence of distinct englacial or superglacial till. The prevalent low percentages of foreign material, and high percentages of material which may have been derived from formations at comparatively short distances from the places of deposition, are just what would be expected in subglacial till. In more than 86 per cent of the analyses, material which might have been derived not more than 50 or 75 miles from the places of deposition constitutes 80 per cent or more of the drift.

There is, however, a certain part of the drift which appears to be very largely of englacial origin. This is the deposit of bowlders upon the surface of the drift sheet. Within the limits of the bowlder fans leading out from the Waterloo quartzite knobs in the area of the Green Bay Glacier, the local material forms a high percentage of the surface bowlder deposit. At many places there are bowlders of the local limestones, but they are generally few in number. There is a very much scattered train of bowlders of coarse, granular limestone, resembling that found in the ancient reefs of the Niagara formation, in the vicinity of Wauwatosa. This train may be traced southwestward from the vicinity of Wauwatosa for some distance, and the blocks were not improbably derived from the rock in this locality. Taken as a whole, however, the amount of local material in the surface bowlder deposit is very small. Accurate determination of percentages has not been made, but tne distribution of the deposit has been mapped in considerable detail, and the character of the bowlders has been carefully observed.

The writer confidently asserts that, excluding the quarzite bowlder fans, less than 10 per cent of the hundreds of thousands of bowlders scattered over the area are of other than foreign crystalline rocks. With these, at a few places, is considerable brown sandstone, probably from the Potsdam group of the Lake Superior region. It thus appears that the percentages of local and foreign material in the drift sheet and in the bowlder deposit upon its surface stand almost in inverse ratio. This bowlder deposit, lying as it does upon the surface of the drift sheet, and being composed so largely of material entirely foreign to the southeastern part of the State, seems clearly to be englacial drift. So far as the writer's observations have gone, this is the only part of the drift deposit which can with any certainty be regarded as of other than subglacial origin.

Noticeable among the surface erratics of the pre-Wisconsin drift area, because of the striking color which renders their identification easy, are bowlders of red quartz-porphyry. These are especially frequent in the older drift area east of Rock River. Though present in the later drift, they are much less frequently seen than in the older drift. These are believed to have been derived from the pre-Cambrian formations north of Lake Huron, whence they were brought to this area by the southwesterly movement of the earlier glaciers.

DISTRIBUTION OF THE LOCAL MATERIAL OF THE DRIFT.

PRE-WISCONSIN DRIFT.

In considering the distribution of the local material of the drift, frequent reference should be made to the accompanying tables of analyses, to Pl. XV, showing the distribution of these analyses, and to Pl. I, which shows the relations of the late Wisconsin glaciers to the geological structure of the eastern part of the State.

A glance at Table A shows how general is the presence of local material of easterly derivation (that from the Niagara limestone) in the pre-Wisconsin drift. This is represented especially by the Niagara limestone, which is sometimes present in considerable amounts, even west of Sugar River, in the towns of Decatur, Spring Grove, and Jefferson, in Green County.

This evidence of westerly or southwesterly movement of the earlier glaciers is in consonance with that afforded by striæ observed in the vicinity of Janesville and Beloit, and with the striæ and drumloidal ridges found in the older drift area east of Rock River.

The largest single element of this drift is from the Trenton group, as would be expected from its wide distribution in the area of the older drift. The Galena and Trenton together constitute more than 50 per cent of the material examined.

The subject of the derivation and distribution of the quartzite drift of the pre-Wisconsin area requires an extended discussion and the consideration of questions which have not been fully solved, so that it has been thought best to leave this very interesting and important element entirely out of the present discussion. The same omission is made in regard to the quartzite bowlder trains of the Green Bay Glacier. This subject has been discussed by Mr. Ira M. Buell, in a paper before the Wisconsin Academy of Science, Arts, and Letters.[a]

DRIFT OF THE GREEN BAY GLACIER.

The direction of the axial movement in the Green Bay Glacier and of the lines of deployment in the southern end of the lobe, as shown by the drumlins and striæ, was in general parallel to the strike of the Paleozoic formations which were overridden (Pl. I). In consequence of this, the local drift material is distributed in more or less clearly marked belts, corresponding in arrangement to that of the underlying rock formations. Since the lines of flowage did not correspond exactly to the trend of the outcropping belts of the several formations, and since the area appears to have been traversed by an earlier glacial movement of more southwestward trend, there is considerable mixing of the local material throughout the several belts. Nevertheless, it is remarkable how quickly and distinctly the passage from one of these Paleozoic belts to that of a higher or lower formation manifests itself by a change in the composition of the drift. This change in the character of the drift in passing across the Green Bay drift from east to west is readily seen from an inspection of Tables B, C, D, and E. These tables show the composition of the drift of the Johnstown terminal moraine, the Milton terminal moraine, the ground moraine of the Green Bay Glacier, and the interlobate Kettle moraine, respectively. As will be seen from the index map, Pl. XV, the analyses are arranged in the several tables in the order of their location from east to west.

In the Kettle moraine (Table E), where it lies close to or upon the west margin of the Niagara formation, the predominant constituent is Niagara limestone. Though not shown in this table, material from the Cincinnati shale is also abundant in some parts of this moraine. The Galena and Trenton limestones, not discriminated here, form a large part of the drift contributed by the Green Bay Glacier. Westward along the Johnstown moraine (Table B), the Niagara constituent decreases until it almost disappears on crossing Rock River in the town of Janesville. In the Milton moraine (Table C) it does not appear in the estimates west of the town of Lima. In the ground moraine (Table D) Niagara limestone is the principal constituent in the towns of Ottawa, Eagle,

[a] Buell, Ira M., Bowlder trains from the outcrops of the Waterloo quartzite area: Trans. Wisconsin Acad. Sci., Arts, and Let., vol. 10, 1895, pp. 485-509.

Sullivan, and Palmyra, though the Galena and Trenton limestones are not shown separately in the table. So large is the Niagara ingredient as to give rise to a suggestion that the front of the Lake Michigan Glacier might have advanced farther west than the line of the Kettle moraine before the Green Bay Glacier had fully developed. It seems more probable, however, that a part of this westerly distribution was due to the earlier advances of the ice, or it may be that this material was derived farther north, where the Niagara formation has a more westerly extension. (See Pl. I, p. 12.)

As the Niagara constituent decreases on going westward, the Galena limestone increases, becoming the predominant element until the zone is reached where the Trenton limestone is exposed by erosion in the pre-Glacial Rock River Valley and its tributaries in the towns of Jefferson, Koshkonong, Milton, and Harmony.

The Trenton limestone is generally the largest ingredient of the drift in the region west of the pre-Glacial Rock River Valley. The Lower Magnesian limestone does not become a recognizable constituent until the region of its exposure in the pre-Glacial Yahara or Catfish basin of southern Dane County is reached.

The sandstone element, though generally present, is probably not accurately shown in the tables. Owing to the friable character of the sandstones, as has been stated, their contribution was generally more to the finer material of the drift than to the coarser material from which the analyses shown in the tables were made. The prevalent character of the finer material of the till is that of a rock flour derived from the abrasion of limestones and shales.

On passing westward from Rock River the increased contribution from the sandstone formation is evident in the more arenaceous character of the drift. With the increase of arenaceous material the till becomes less compact and the effects of leaching and oxidation extend to greater depths. The more compact till of the limestone districts is rarely leached of its lime carbonate to greater depths than 1 or 2 feet, while the effects of oxidation are manifest only in the change of the color of the upper part of the till from bluish gray to light buff. In the more arenaceous parts the carbonates may be removed to depths of 3 to 5 feet, or even more, while the color of the upper part of the drift has been changed from buff to brownish, and the buff color extends to greater depths. This difference is worthy of note, especially in making comparisons of the evidences of age in the earlier and the later drift sheets. In the discussion of the pre-Wisconsin drift east of Rock River it was stated that this drift was thoroughly leached of its calcareous elements to a depth of 3 or 4 feet, sometimes to a depth of 5 feet or more, while oxidation had stained the upper 3 or 4 feet to a brownish or a yellowish brown color. Even so far west as the margin of the drift area, near Monroe, in Green County, the depths of leaching noted in clayey till were generally not more than 3 or 4 feet, and nowhere more than 7 feet.

It is thus apparent that it is important to note the composition and texture of the drift when drawing inferences as to the relative age of the drift sheets from the amount of leaching and oxidation accomplished.

The percentages of Huronian quartzite shown in the Tables B, C, and D are not to be taken as a true exposition of the quartzite content of the drift within the quartzite bowlder fans. A large number of estimates of this quartzite content were made by Mr. Ira M. Buell during his study of the bowlder fans derived from the Waterloo outcrops. Several other estimates were made by the writer in northern Rock County and eastern Dane County, but as these were to determine the actual amounts of quartzite material rather than the percentages of the different rock constituents of the drift, they have been omitted from the tables. As has been stated, the full discussion of the quartzite drift is not taken up in this paper.

DRIFT OF THE DELAVAN LOBE AND OF THE MAIN LAKE MICHIGAN GLACIER.

Passing now to the consideration of the drift of the Delavan lobe and the main Lake Michigan Glacier, as shown in Tables H, I, J, and K, we see that the composition is considerably different from that of the Green Bay Glacier. The Niagara limestone is everywhere the predominant constituent of the drift. Material derived from the lower horizons of the Paleozoic formations is present in notable amount only in those parts of the Elkhorn and Darien moraines which lie across the pre-Glacial Troy Valley, in whose slopes the Cincinnati shales, the Galena limestone, and probably also the Trenton limestone were exposed. The Niagara constituent stands as follows:

Niagara limestone in the drift of the Lake Michigan Glacier.

	Per cent.
Darien moraine of Delavan lobe	60.69
Elkhorn moraine of Delavan lobe	64.05
Valparaiso moraine of Lake Michigan Glacier	86.724
Lake-border morainic system of Lake Michigan Glacier	76.63
Averages of 82 analyses	69.31

The difference between the drift of the Delavan lobe and that of the Green Bay Glacier begins to show itself in the interlobate deposit northeast of Richmond, as will be seen by comparing Tables B and H. Analyses 1–6, Table B, were made on the Green Bay side of this deposit. Analyses 1–9, Table H, were made on the Delavan side of the same deposit. Though there was doubtless considerable mixing of the drift of the two glaciers in this tract, yet the analyses show a marked difference in the percentages of Niagara limestone.

That the Galena and Trenton limestones should appear in so large percentages as they do in more than 40 different analyses of the drift of the Darien and Elkhorn moraines seems remarkable, considering the limited extent of the exposure of these formations within the area of the Delavan lobe, and considering that the material examined was taken at the surface of the drift, 100 to several hundred feet higher than the levels at which the rock formations were exposed to glacial action. The average percentages of Galena and Trenton limestone in those parts of the Darien and Elkhorn moraines lying across the pre-Glacial Troy Valley northwest of Lake Geneva are as follows:

Average amounts of Galena and Trenton limestones in parts of Darien and Elkhorn moraines.

	Per cent.
Darien moraine	25.10
Elkhorn moraine	18.54

It seems hardly possible, however, to ascribe all the amounts shown in the 42 analyses to errors in identification, or to a mixing of the drift of the Green Bay Glacier with that of the Delavan lobe. Each of these factors may enter into the results shown, but there still remains evidence that considerable material was derived from the Galena and Trenton formations exposed in Troy Valley and brought to a position for deposition in the upper part of the moraines within a few miles of the limit of the advance. It is, of course, possible that this material was picked up by the earlier glaciers and was taken from earlier drift by the Delavan lobe and redeposited.

Following the Darien and Elkhorn moraines eastward about Lake Geneva, into the Niagara province, through the towns of Walworth, Linn, Bloomfield, Geneva, Lyons, and Burlington, the Galena and Trenton constituents disappear from the analyses and the contribution from the Niagara group becomes generally 70 to 90 per cent.

In the material examined from the Valparaiso morainic system (Table J) the Niagara constituent does not fall below 82 per cent.

A part of this Niagara constituent, which is clearly very local in its derivation, consists of fragments of red argillaceous limestone. The only exposures of these red beds in situ is in a quarry 1 mile southwest of Burlington, but their presence in the lower part of the Niagara formation in western Racine and Kenosha counties is shown by numerous wells. This red material is generally present in the drift of western Racine and Kenosha counties and in eastern Walworth County. Analyses within the western half of the Niagara province frequently show 1 to 3 or more per cent of this material.

The drift in the lake-border belt (Table K) contains, in addition to the Niagara material, thin-laminated, brittle limestone from deposits exposed near Milwaukee, referred to the Salina formation, and fragments of the hydraulic limestones and blue and black shales of the Hamilton group which occur in the same vicinity.

OUTWASH DEPOSITS.

It has already been noted that the drift of the outwash deposit associated with the formation of the Darien and Johnstown moraines is intermediate in character between that of the moraines which it borders in regard to the percentages of foreign material. This is a consequence of the intermingling of the detritus-bearing waters from the Delavan and Green Bay ice fronts.

The results of this commingling are even more plainly seen in the distribution of the local constituents. Table G shows the analyses of the drift of this outwash deposit. It will be seen by referring to this table that the Niagara material is very generally distributed through the deposit, being shown by all the analyses except the one made in the town of Union, the most northwesterly township of Rock County. The Niagara constituent, however, nowhere reaches 20 per cent, except in those parts which received the discharge directly from the front of the Delavan lobe, as shown by analyses 39 and 40, Table G, or in those parts of Bradford, La Prairie, Turtle, Rock, and Beloit townships which were reached by the Darien waters from this lobe passing through the Turtle Creek gorge, in southern Bradford Township. (See analyses 22, 28, 29, 30, 32, and 34–41.) As has been previously noted, the larger percentages of Niagara material in these parts is one evidence that outwash material from the Darien moraine was actually carried through the rock gorge by the escaping waters.

The predominant constituent of the coarser outwash drift, as would be expected, is Trenton limestone, with which is considerable drift showing the characteristics of the Galena limestone. Sandstone pebbles are generally present, as is also a large ingredient of loose quartz sand. In some parts the deposit is mostly sand. Quartzite pebbles are generally distributed, though in small amounts.

Table F shows a few analyses of the outwash deposits formed behind the Darien moraine which border the Elkhorn and Milton moraines near their point of junction. As has been stated, the disposition of this deposit indicates that the outwash was principally from the Green Bay Glacier. The percentages of Niagara limestone shown in Table F are intermediate between the low percentages of Niagara material in the Milton moraine in Whitewater Township and the high percentages of material from the same formation in the Elkhorn moraine. This indicates a mixture of drift of the Delavan lobe and of the Green Bay Glacier by the waters from the interlobate angle near Lagrange and from the contiguous ice fronts.

LESS COMMON CONSTITUENTS OF THE DRIFT.

COPPER, IRON, MARCASITE, AND DIAMONDS.

Among the less common of the foreign ingredients in the drift of this area are pieces of metallic copper from the Lake Superior regions. These specimens, popularly known as "float copper" or "drift copper," are found not infrequently, though they are by no means abundant. They vary from a few ounces to several hundred pounds in weight. A farmer living near the village of Caldwell Prairie, in northwestern Racine County, informed the writer that he had at one time plowed up on his land a piece of float copper weighing over 500 pounds.

Occasional pebbles of ferruginous sandstone and other iron ores occur within and upon the surface of the drift.

The writer has found a few nodules of marcasite in the drift near Milwaukee. These have a radiating crystalline structure.

Foreign elements of great interest as well as of rare occurrence in the drift are the diamonds which have been found at several places in southeastern Wisconsin. Three of these stones were found within the area under discussion. The first was found in or near the village of Eagle, in southwestern Waukesha County, in 1876; another, on the farm of Judson Devine, 2½ miles southwest of the village of Oregon, in Dane County, in October, 1893; while a third was found near Burlington, Racine County, at a time which has not been ascertained.

These, as well as other diamonds found in the glacial drift of the region of the Great Lakes, have been described, and their mode of occurrence discussed, by Prof. William H. Hobbs.[a] Professor Hobbs gives a probable explanation of the diamond distribution, and discusses the subject of a probable source of derivation east of James Bay, with references to other publications. The accompanying data concerning the Eagle, Oregon, and Burlington stones are from this article by Professor Hobbs:

[a] Hobbs, Wm. H., The diamond field of the Great Lakes: Jour. Geol., vol. 7, 1899, pp. 375-388.

Data regarding diamonds in the glacial drift.

Locality.	Weight.	Crystal form.	Surface markings.	Color.	Date of finding.	Date of determination, and by whom.	Finder.	Material in which found.	Present owner.	Where described.
	Carats.									
1. Eagle, Waukesha County, Wis.; farm owned (1876) by Thomas Devereaux.	$15\frac{13}{32}$	Rhombic dodecahedron, with vicinal faces of hexoctahedron. Only slightly distorted.	Faces show circular markings, also triangular elevations.	Cape white, pale yellow.	——, 1876	G. F. Kunz, 1883; W. H. Hobbs, 1893.	Laborer employed by Mrs. Clarissa Wood, of Eagle.	Gravel and clay of Kettle moraine cemented by ferric oxide into a hard yellow matrix.	Tiffany & Co., New York.	Am. Geology, vol. 14, 1894, p. 31; Neues Jahr. für Mineral., 1896, vol. 2, p. 249.
2. 2¼ miles southwest of Oregon, Dane County, Wis., on farm owned by Judson Devine.	$3\frac{14}{16}$	Rhombic dodecahedron (distorted).	Deeply pitted with circular and elongated reniform markings.	White, with slight gray-green tinges (probably surficial).	Oct. —, 1893	W. H. Hobbs, 1893; later by G. F. Kunz.	Son of Charles Devine, Oregon.	With pebbles of quartz in clay, in Kettle moraine.	.....do........	Am. Geology, vol. 14, 1894, p. 31; Neues Jahr. für Mineral., 1896, vol. 2, p. 249; Mineral Resources U. S. for 1893, U. S. Geol. Survey, 1894, p. 682.
3. Burlington, Racine County, Wis.	$2\frac{1}{16}$	Elongated tetrahedral twin.	....	Faint greenish white, perhaps external.	....	Bunde & Upmeyer, Milwaukee, 1893.	Mrs. G. Pufahl, of Burlington.	In Kettle moraine.	Bunde & Upmeyer, Milwaukee.	Eighteenth Ann. Rept. U. S. Geol. Survey, pt. 5, 1897, p. 1183.

The occurrence of the three stones found in the area under discussion was as follows: The Oregon diamond was found about one-half mile inside the outer margin of the outer or Johnstown terminal moraine of the Green Bay Glacier, at a point about 3 miles northwest of the northwest corner of Rock County, where the moraine enters Dane County from the southeast. The Eagle diamond was found in the interlobate Kettle moraine, or the closely bordering outwash deposits of the upper terrace, in or near the village of Eagle, in southwestern Waukesha County. The exact location of the Burlington find is not known, although the stone is believed to have come from the terminal-moraine deposits of the Lake Michigan Glacier or of the Delavan lobe of the same in the vicinity of Burlington. The approximate locations are shown on Pl. XV. These, like all the other drift diamonds of the region of the Great Lakes, occur in the terminal moraines of the late Wisconsin glaciers or in the attendant outwash deposits.

Professor Hobbs states that of the seventeen diamonds which have been found in the glacial drift of the Great Lakes region, three of the stones (including the two of largest size) remained in the hands of the farming population without their nature being discovered for periods of eight and one-half, seven, and more than fifteen years, respectively, so that it is not at all improbable that others now lie in the little collections of "pretty stones" and local curios which adorn the clock shelves of the country farm houses. Doubtless also many others still lie buried in the drift. That they are, however, of infrequent occurrence may be inferred from the writer's own experience. He has not discovered a single diamond in several seasons' examination of the drift in all of its aspects within the area. He has not, however, made a special search for them.

SUMMARY.

In conclusion, a few of the salient features of this discussion of the lithological composition of the drift of this part of southeastern Wisconsin may be pointed out.

The drift of the area is predominantly of local character, some of it apparently having its place of derivation within a few miles of the place of final deposition. This local material constitutes about 87 per cent of the material examined.

About 13 per cent of the material examined must have traveled several hundred miles to reach its destination. Some of the foreign material may have made part of the journey at earlier stages of glaciation.

The relative amounts of local and foreign material in the body of the drift and in the bowlder deposit on its surface stand in almost inverse ratio, the surface bowlders being predominantly foreign. From this fact, and from their occurrence at the top of the drift deposit, the surface bowlders are probably to be regarded as englacial drift.

The distribution of the local material is in conformity with other evidence of the manner of deployment of the glaciers. The several local constituents of the drift of the Green Bay Glacier are distributed through overlapping belts, whose arrangement from east to west corresponds to that of the outcropping belts of the several Paleozoic formations from which they are derived. There has also been more or less westward shifting of this material, due very largely to the general westerly movement of the earlier glaciers.

The drift of the Lake Michigan Glacier is predominantly Niagara limestone, but where the Delavan lobe crossed the pre-Glacial Troy Valley considerable Galena and Trenton material was introduced. In western Racine and Kenosha counties and eastern Walworth County the red beds of the lower part of the Niagara group manifest themselves by their contribution to the drift, though they are exposed at but one point, near Burlington. The Salina and Hamilton formations contribute to the drift of the lake-border belt, but they appear not to have sent much material farther west.

There is little essential difference in lithological composition between the pre-Wisconsin and the later drift of the Lake Michigan Glacier. It shows, however, a much more westerly distribution of the Niagara limestone than occurs in the Green Bay Glacier. The Niagara material west of Sugar River in Green County agrees with the striae observed near Janesville and Beloit, and with the drumloidal trend of the older drift hills in eastern Rock and western Walworth counties, in being evidence of the westerly movement of the earlier glaciers. This is a matter of special moment in the consideration of the derivation of the quartzite pebbles and bowlders of the older drift area.

So far as the writer's observations have gone, there appears to be no essential difference between the drift of the terminal moraines, outwash, ground moraines, and drumlins, in the relative amounts of local and foreign material. In all these features the predominant local character of the drift indicates a subglacial origin of the component material.

TABLES SHOWING LITHOLOGICAL COMPOSITION OF THE DRIFT OF A PORTION OF SOUTHEASTERN WISCONSIN.

TABLE A.—*Pre-Wisconsin drift.*

Number of analysis	1	2	3	4	5	6	7	8	9	10	11	12	13
Town	Sharon (T. 1 N., R. 15 E.).		Darien (T. 2 N., R. 15 E.).	Clinton (T. 1 N., R. 14 E.).	Bradford (T. 2 N., R. 14 E.).	La Prairie (T. 2 N., R. 13 E.).	Janesville (T. 3 N., R. 12 E.).						
Section	25	6	32	4	5	15	23	27	21	20	18	29	33
Fraction	SE. ¼	SW. ¼	SE. ¼	SE. ¼	SW. ¼	E. ½	......	......	......	......	......	......	......
Niagara limestone		62½			29	11	9	35	13	15	26	82	19
Galena limestone	82¾			97	56	15	......	1	1	......	......	......	7
Trenton limestone		16½	75		......	40	52	40	65	67	55	9	57
Lower Magnesian limestone (including Mendota limestone)	......	......	......	......	......	......	......	......	......	......	......	......	......
St. Peter and Potsdam sandstone	½	2½	3	......	......	5	5	5	......	3	......	......	4
Huronian quartzite	¾	......	......	......	......	......	......	......	1	......	1	1	2
Archean crystalline rocks	13½	18½	22	3	15	15	19	11	18	8	8	6	6
Chert and quartz	2½	......	......	......	......	8	3	......	2	2	4	......	2
Doubtful, mostly limestone	......	......	......	......	......	6	12	8	......	5	6	2	3
Proof	100	100	100	100	100	100	100	100	100	100	100	100	100
Percentage of foreign material	13½	18½	22	3	15	15	19	11	18	8	8	6	6

Number of analysis	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
Town	Rock (T. 2 N., R. 12 E.).		Beloit (T. 1 N., R. 12 E.).				Center (T. 3 N., R. 11 E.)					Plymouth (T. 2 N., R. 11 E.).			
Section	6	18	5	21	28	27	25	33	31	30	30	1	10	20	33
Fraction	......	......	......	......	......	......	......	......	......	......	NW.	......	......	......	......
Niagara limestone	32	4	27	22	26	33½	22	23	13	22	27	19	14	15	15
Galena limestone	......	3	11	9	9	14½	......	......	......	......	4	1	......	10	2
Trenton limestone	53	54	48	47	50	34	50	53	42	46	44	64	48	53	64
Lower Magnesian limestone (including Mendota limestone)	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......
St. Peter and Potsdam sandstone	......	6	1	5	1	1½	1	1	9	3	2	......	3	3	2
Huronian quartzite	......	1	......	......	......	......	......	......	......	......	......	......	......	2	......
Archean crystalline rocks	12	12	5	14	7	7½	17	12	13	11	6	3	15	9	7
Chert and quartz	......	14	1	1	......	......	2	......	......	......	3	3	7	3	2
Doubtful, mostly limestone	3	6	7	2	7	9	8	11	23	18	14	10	13	5	8
Proof	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Percentage of foreign material	12	12	5	14	7	7½	17	12	13	11	6	3	15	9	7

TABLE A.—*Pre-Wisconsin drift*—Continued.

Number of analysis	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	
Town	Newark (T. 1 N., R. 11 E.).		Spring Valley (T. 2 N., R. 10 E.).			Avon (T. 1 N., R. 10 E.).	Decatur (T. 2 N., R. 9 E.).		Spring Grove (T. 1 N., R. 9 E.).				Jefferson (T. 1 N., R. 8 E.).	Brooklyn (T. 4 N., R. 9 E.).		Averages (Niagara, Galena, and Trenton approximate).
Section	8	29	12	13	17	24	26	21	5	29	28	32	12	24	21	
Fraction	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	
Niagara limestone	1	.....	5	7	17	17	29	4	29	25	10	.....	62	7	23	21.30
Galena limestone	.....	.....	2	.....	1	.....	.....	.....	.....	8	29	2	.....	.....	5	3.63
Trenton limestone	82	28	62	64	61	69	32	61	15	30	52	56	8	21	43	48.59
Lower Magnesian limestone (including Mendota limestone)	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
St. Peter and Potsdam sandstone	1	3	4	6	1	.....	2	14	3	.....	.....	2	.....	9	.....	2.58
Huronian quartzite	.....	.....	.....	.....	.....	1	3	.....	.....	2	1	.....	.....	6	1	.529
Archean crystalline rocks	4	18	14	10	3	8	14	9	13	3	4	7	6	50	21	11.55
Chert and quartz	1	2	2	7	1	1	6	5	2	.....	1	4	2	5	.....	2.29
Doubtful, mostly limestone	10	49	11	6	16	4	14	7	38	32	3	29	22	2	7	10.09
Proof	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100.559
Percentage of foreign material	4	18	14	10	3	8	14	9	13	3	4	7	6	50	21	11.55

TABLE B.—*Johnstown terminal moraine of the Green Bay Glacier.*

Number of analysis	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Town	Whitewater (T. 4 N., R. 15 E.).	Richmond (T. 3 N., R. 15 E.).						Johnstown (T. 3 N., R. 14 E.).				Harmony (T. 3 N., R. 13 E.).		
Section	25	35	3	9	17	17	7	11	22	17	7	1	15	8
Fraction	SW. ¼	SE. ¼	S. ½	SE. ¼	N. ½	S. ½	NE. ¼	SE. ¼	Mid.	SW. ¼	SW. ¼	NW. ¼	NE. ¼	SW. ¼
Niagara limestone	28	55	35	2	12	5	5½	7	2	3	6	9	6	8
Galena limestone	35	.....	36	69	70	73½	81½	69	} 90¾ {	77	79	67	63	10
Trenton limestone	24	25	10	.....	4	10½	6	11		2	5	9	15	72
Lower Magnesian limestone (including Mendota limestone)	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
St. Peter and Potsdam sandstone	2	.....	2	1	1	½	½	2	.....	3	1	1	1	2
Huronian quartzite	.....	.....	3	.....	.....	½	½	2	.....	.....	.....	.....	1	1
Archean crystalline rocks	11	20	8	16	13	5½	5½	6	7	11	9	11	12	7
Chert and quartz	.....	.....	5	3	.....	½	½	2	¼	4	.....	1	2	.....
Doubtful, mostly limestone	.....	.....	1	9	.....	4	.....	1	.....	.....	.....	2	.....	.....
Proof	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Percentage of foreign material	11	20	8	16	13	5½	5½	6	7	11	9	11	12	7

TABLE B.—*Johnstown terminal moraine of the Green Bay Glacier*—Continued.

Number of analysis	15	16	17	18	19	20	21	22	23	24	25	26	27	Averages (Galena, Trenton, and Lower Magnesian approximate).
Town	Milton (T. 4 N., R. 13 E.).		Janesville (T. 3 N., R. 12 E.).	Center (T. 3 N., R. 11 E.).		Union (T. 4 N., R. 10 E.).	Rutland (T. 5 N., R. 10 E.).		Oregon (T. 5 N., R. 9 E.).				Montrose (T. 5 N., R. 8 E.).	
Section	33	30	9	12	4	22	30	4	25	22	13	8	1	
Fraction	SE. ¼	SE. ¼	....	....	NW. ¼	SW. ¼	NE. ¼	SW. ¼	NW. ¼	W. ½	NW. ¼	S. ½	....	
Niagara limestone	13	13	8	2	......	3	......	......	......	1	......	2	....	8.33
Galena limestone	39	25	2	2	......	......	......	......	......	....	......	......	....	30.69
Trenton limestone	25	43	58	32	65	56	29	} 75	34	66	37	29	61	29.01
Lower Magnesian limestone (including Mendota limestone)	......	......	......	......	6	20	28		20	13	25	35	12	6.11
St. Peter and Potsdam sandstone	5	6	1	4	9	11	39	17	36	12	20	22	7	7.629
Huronian quartzite	1	......	5	9	3	1	2	......	1	....	1	1	....	1.85+
Archean crystalline rocks	15	11	20	9	12	6	2	8	7	8	14	11	6	10.03
Chert and quartz	......	......	6	2	......	......	......	......	......	....	......	......	....	.944+
Doubtful, mostly limestone	2	2	....	40	5	3	......	......	2	....	3	......	14	3.25+
Proof	100	100	100	100	100	100	100	100	100	100	100	100	100	97.363
Percentage of foreign material	15	11	20	9	12	6	2	8	7	8	14	11	6	10.03

TABLE C.—*Milton terminal moraine of the Green Bay Glacier.*

Number of analysis	1	2	3	4	5	6	7	8	9	10	11	12	13
Town	La Grange (T. 4 N., R. 16 E.).			Whitewater (T. 4 N., R. 15 E.).			Lima (T. 4 N., R. 14 E.).			Milton (T. 4 N., R. 13 E.).			
Section	9	18	18	24	26	32	14	14	22	12	25	23	30
Fraction	SW. ¼	SE. ¼	Mid.	W. ½	NW. ¼	SE. ¼	NE. ¼	SE. ¼	SE. ¼	NW. ¼	NW. ¼	W. ½	NW. ¼
Niagara limestone	29½	25	20	7½	6	6	7	10½	7	......	......	......	......
Galena limestone	} 57½	63	67	43	63	67	70	70½	80	43	45	55	25
Trenton limestone				22	22	10	10	4	2	39	19	26	43
Lower Magnesian limestone (including Mendota limestone)	......	......	......	......	......	......	......	......	......	......	......	......	......
St. Peter and Potsdam sandstone	1	1	3	5½	2	2	1	1½	1	3	1	4	6
Huronian quartzite	......	......	......	......	......	......	......	......	......	1	......	1	......
Archean crystalline rocks	12	11	9	21	7	15	11	13½	10	11	15	12	11
Chert and quartz	......	......	......	......	......	......	......	......	......	1	2	2	2
Doubtful, mostly limestone	......	1	1	1	......	......	1	......	......	2	18	......	13
Proof	100	100	100	100	100	100	100	100	100	100	100	100	100
Percentage of foreign material	12	11	9	21	7	15	11	13½	10	11	15	12	11

TABLE C.—*Milton terminal moraine of the Green Bay Glacier*—Continued.

Number of analysis	14	15	16	17	18	19	20	21	
Town	Fulton (T. 4 N., R. 12 E.).			Dunkirk (T. 5 N., R. 11 E.).	Porter (T. 4 N., R. 11 E.).	Pleasant Sp. (T. 6 N., R. 11 E.).	Fitchburg (T. 6 N., R. 9 E.).		Average (Galena, Trenton, and Lower Magnesian approximate).
Section	3	16	5	36	3	32	26	35	
Fraction	NW. ¼	NW. ¼	SW. ¼	NW. ¼	SW. ¼	NE. ¼	SE. ¼	....	
Niagara limestone	....	....	....	....	....	....	....	....	5.64
Galena limestone	....	....	....	....	....	....	....	....	37.43
Trenton limestone	85⅓	90	79	76	79	85	....	31	29.55
Lower Magnesian limestone (including Mendota limestone)	....	....	....	3	....	....	57	42	2.14
St. Peter and Potsdam sandstone	3⅓	....	4	3	5	4	21	20	4.39
Huronian quartzite	4	2	5	2	8	2	1	....	1.24
Archean crystalline rocks	4⅔	5	9	13	3	6	15	7	10.53
Chert and quartz	2⅔	3	3	....	5	2	5	....	1.31
Doubtful, mostly limestone	....	....	....	3	....	1	1	....	2.
Proof	100	100	100	100	100	100	100	100	94.23
Percentage of foreign material	4⅔	5	9	13	3	6	15	7	10.53

TABLE D.—*Ground moraine of the Green Bay Glacier.*

Number of analysis	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Town	Ottawa (T. 6 N., R. 17 E.)	Eagle (T. 5 N., R. 17 E.).		Sullivan (T. 6 N., R. 16 E.)	Palmyra (T. 5 N., R. 16 E.).			Hebron (T. 6 N., R. 15 E.).				Cold Spring (T. 5 N., R. 15 E.).	Whitewater (T. 4 N., R. 15 E.).	
Section	32	5	6	33	3	14	5	12	25	36	31	19	4	7
Fraction	SE. ¼	NE. ¼	SW. ¼	NE. ¼	NE. ¼	N. ½	SW. ¼	SE. ¼	E. ½	SE. ¼	W. ½	NW. ¼	NE. ¼	W. ½
Niagara limestone	81	84	82⅔	84	78	82	80½	.....	....	.....	11	21⅓	5	4
Galena limestone	.....	.....	.....	.....	.....	....	.....	79	89½	90	10	18⅓	56	44
Trenton limestone	.....	.....	.....	.....	.....	....	.....	.....	....	.....	25	44⅔	15	39
Lower Magnesian limestone (including Mendota limestone)	.....	.....	.....	.....	.....	....	.....	.....	....	.....	.....	.....	.....	.....
St. Peter and Potsdam sandstone	.....	.....	1	2	.....	....	3	.....	1	1	21	⅔	3	1
Huronian quartzite	.....	2	⅓	.....	.....	½	.....	1	....	.....	.....	⅓	1	.....
Archean crystalline rocks	19	14	16	14	22	16	16½	20	9½	9	32	12⅔	11	12
Chert and quartz	.....	.....	.....	.....	.....	....	.....	.....	....	.....	.....	.....	.....	.....
Doubtful, mostly limestone	.....	.....	.....	.....	.....	1½	.....	.....	....	.....	1	2	9	.....
Proof	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Percentage of foreign material	19	14	16	14	22	16	16½	20	9½	9	32	12⅔	11	12

TABLE D.—*Ground moraine of the Green Bay Glacier*—Continued.

Number of analysis	15	16	17	18	19	20	21	22	23	24	25	26
Town	Lima (T. 4 N., R. 14 E.).		Koshkonong (T. 5 N., R. 14 E.).									
Section	2	3	36	13	10	22	22	27	34	20	32	32
Fraction	NE. ¼	SW. ¼	Mid	N. ½	SE. ¼	Mid	W. ½	SW. ¼	NW. ¼	SE. ¼	SW. ¼	NE. ¼
Niagara limestone	8	11	15	26	23	36	15	11	10	5	7	15
Galena limestone	59	49	51	4	12	15	39	27¼	30	18	55	43
Trenton limestone	23	34	28	60	42	42	33	49	51	51	33	38
Lower Magnesian limestone (including Mendota limestone)												
St. Peter and Potsdam sandstone					5	1	3	1½		2		
Huronian quartzite							2	1				
Archean crystalline rocks	10	6	5	8	13	5	8	6½	9	8	5	4
Chert and quartz												
Doubtful, mostly limestone			1	2	1			3¾		16		
Proof	100	100	100	100	100	100	100	100	100	100	100	100
Percentage of foreign material	10	6	5	8	13	5	8	6½	9	8	5	4

Number of analysis	27	28	29	30	31	32	33	34	Averages (Niagara, Galena, and Trenton approximate).
Town	T. 5 N., R. 13 E.	Jefferson (T. 6 N., R. 14 E.	Oakland (T. 6 N., R. 13 E.).		Albion (T. 5 N., R. 12 E.).	Dunkirk (T. 5 N., R. 11 E.).	Pleasant Spring (T. 6 N., R. 11 E.).		
Section	36	7	9	16	22	11	24	24	
Fraction	SE. ¼	SW. ¼	SE. ¼	NW. ¼	SW. ¼	SW. ¼	SW. ¼	SE. ¼	
Niagara limestone	14						½		11.11+
Galena limestone	24	33	}						25.51+
Trenton limestone	47	42	77 }	77	83⅔	85⅓	90	86½	48.61+
Lower Magnesian limestone (including Mendota limestone)					1⅔	3	2		.19
St. Peter and Potsdam sandstone	3	2	2		2⅓	3⅓	1½	2	1.83+
Huronian quartzite	2	1	2	6	4	1⅔	1	1	.82
Archean crystalline rocks	9	14	12	16	8	5⅓	5	8	11.42+
Chert and quartz	1			1	⅓	⅔		2	.11+
Doubtful, mostly limestone		8	7			⅔		½	1.56
Proof	100	100	100	100	100	100	100	100	101.16+
Percentage of foreign material	9	14	12	16	8	5⅓	5	8	11.42+

TABLE E.—*Interlobate Kettle moraine.*

Number of analysis	1	2	3	4	5	6	7	8	9	10	11	12	Averages.
Town	Genesee (T. 5 N., R. 18 E.).		Eagle (T. 5 N., R. 17 E.)					Palmyra (T. 5 N., R. 17 E.).					
Section	5	30	21	21	20	20	30	23	26	26	27	33	
Fraction	Mid.	NE. ¼	Mid.	SW. ¼	SE. ¼	SW. ¼	W. ½	SE. ¼	W. ½	SW. ¼	SW. ¼	SW. ¼	
Niagara limestone	80	78½	62	60	54	57	62	58	58⅓	43⅓	53¼	43	59.13
Galena and Trenton limestone	......	......	13	18	23	20	12½	26	20	39⅓	23	26	18.40
Lower Magnesian limestone (including Mendota limestone)	......	......	......	......	......	......	......	......	......	......	......	......	......
St. Peter and Potsdam sandstone	1⅛	1½	2	2	2	......	5	2	1⅓	1⅔	2	15	3.00
Huronian quartzite	⅜	½	......	......	......	......	½	......	......	⅓	......	......	.16
Archean crystalline rocks	16⅝	19½	18½	20	18	17	14½	12½	15⅓	14⅓	13¼	12	15.99
Chert and quartz	⅘	......	......	......	1	......	......	1	1	......	......	......	.316
Doubtful, mostly limestone	⅜	......	4½	......	2	6	5½	⅛	3⅔	1	8	4	2.98
Proof	100	100	100	100	100	100	100	100	100	100	100	100	99.98
Percentage of foreign material	16⅘	19½	18½	20	18	17	14½	12½	15⅓	14⅓	13¼	12	15.99

TABLE F.—*Outwash deposits bordering the Elkhorn and Milton moraines near their point of junction.*

Number of analysis	1	2	3	4	5	Averages.
Town	Whitewater (T. 4 N., R. 15 E.).		Lagrange (T. 4 N., R. 16, E.).		Sugar Creek (T. 3 N., R. 16 E.).	
Section	24	25	20	21	5	
Fraction	SE. ¼	NE. ¼	SE. ¼	E. ½	W. ½	
Niagara limestone	8⅗	15¾	32½	35	45	27.38
Galena limestone	67⅗	29¼	42½	53	30	44.48
Trenton limestone	13⅗	38¾	3	....	6	12.28
Lower Magnesian limestone (including Mendota limestone)	....	....	....	....	....	....
St. Peter and Potsdam sandstone	1⅓	1½	4	2	2	2.16
Huronian quartzite	⅓	¼	....	....	....	.12
Archean crystalline rocks	5⅓	11¼	16	10	16	11.71
Chert and quartz	....	¼	....	....	....	.05
Doubtful, mostly limestone	3	3	2	....	1	1.6
Proof	100	100	100	100	100	99.78
Percentage of foreign material	5⅓	11¼	16	10	16	11.71

TABLE G.—*Outwash deposits bordering the Darien and Johnstown moraines.*

Number of analysis	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Town	Harmony (T. 3 N., R. 13 E.)						Janesville (T. 3 N., R. 12 E.)							
Section	26	27	33	29	31	7	14	14	15	16	18	25	26	35
Fraction	NE. ¼	S. ½	NW. ¼	N. ½	NE. ¼	S. ½	SE. ¼	SW. ¼	NE. ¼	SE. ¼	Mid.	SW. ¼	NE. ¼	SE. ¼
Niagara limestone	17	15	14	5	1	6	11	12	18	13	5	3	11	11
Galena limestone	16	7	18	6	1	1	......	......	......	......	2	4½	3	......
Trenton limestone	53	60	43	49	71	70	65	79	54	66	67	74	63	58
St. Peter and Potsdam sandstone	1	......	5	11	12	8	8	......	3	7	9	8	3	3
Huronian quartzite	......	1	......	3	......	1	4	......	......	3	1	......	1	5
Archean crystalline rocks	9	8	13	11	7	7	3	9	23	5	6	10½	13	9
Chert and quartz	......	1	......	5	3	3	5	......	......	3	8	½	4	......
Doubtful, mostly limestone	4	8	7	10	5	5	4	......	2	3	2	2½	2	9
Proof	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Percentage of foreign material	9	8	13	11	7	7	3	9	23	5	6	10½	13	9

Number of analysis	15	16	17	18	19	20	21	22	23	24	25	26	27	28
Town	Rock (T. 2 N., R. 12 E.)								La Prairie (T. 2 N., R. 13 E.).					
Section	1	3	14	15	22	26	25	25	3	5	6	19	21	31
Fraction	SE. ¼	NW. ¼	SE. ¼	E. ½	NE. ¼	NE. ¼	SW. ¼	SE. ¼	SW. ¼	NW. ¼	SE. ¼	SE. ¼	NW. ¼	SW. ¼
Niagara limestone	4	8	8	11	12	......	13	20	10	8	16	5	17	20
Galena limestone	......	......	......	1	......	......	......	25	8	2	1	......	12	16½
Trenton limestone	59	69	59	72	63	56	52	32	69	65	53	61	44	27½
St. Peter and Potsdam sandstone	9	4	8	3	7	6	1	4	1	2	......	5	6	1
Huronian quartzite	2	2	2	2	1	2	3	......	1	3	......	2	......	2
Archean crystalline rocks	9	5	12	9	11	14	18	13	12	13	18	13	10	24½
Chert and quartz	12	6	5	2	1	18	1	6	......	1	4	9	4	1
Doubtful, mostly limestone	5	3	6	......	5	4	12	......	5	6	8	5	7	2
Proof	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Percentage of foreign material	9	5	12	9	11	14	18	13	12	13	18	13	10	24½

TABLE G.—*Outwash deposits bordering the Darien and Johnstown moraines*—Continued.

Number of analysis	29	30	31	32	33	34	35	36	37	38	39	40	41	42	Averages (Galena and Trenton approximate).
Town	Beloit (T. 1 N., R. 12 E.).						Turtle (T. 1 N., R. 13 E.).				Richmond (T. 3 N., R. 15 E.).	Darien (T. 2 N., R. 15 E.).	Bradford (T. 2 N., R. 14 E.).	Union (T. 4 N., R. 10 E.).	
Section	1	12	11	23	26	36	20	31	31	2	16	7	31	21	
Fraction	SE. ¼	NE. ¼	NW. ¼	SW. ¼	SW. ¼	SE. ¼	SW. ¼	NE. ¼	SE. ¼	NE. ¼	SW. ¼	SE. ¼	NE. ¼	W. ½	
Niagara limestone	22	21½	4	20	4	32	23½	24½	27	56	31⅔	32	33	.....	14.88
Galena limestone	18	16	7	14	39	14½	18	30	21	.....	36⅓	42	41⅔	49	9.918
Trenton limestone	41	39	45	44	28	33½	40	26½	29	29	8	.....	.....	.....	50.96
Lower Magnesian limestone (including Mendota limestone)	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	29	.69
St. Peter and Potsdam sandstone	2	2½	5	2	4	3	3	3½	2	1	1⅓	1	4	15	4.388
Huronian quartzite	.....	½	1	.....	.....	.....	.....	½	3	½	1⅓	.....	1⅓	.....	1.17+
Archean crystalline rocks	13	17	29	20	22	13	9	13	13	13½	15⅔	19	18⅔	6	12.78
Chert and quartz	1	1	9	.....	2	½	1½	.....	2	.....	1	2	⅔	.....	2.93
Doubtful, mostly limestone	3	2½	.....	.....	1	3½	5	2	3	.....	⅔	4	⅔	1	3.99
Proof	100	100	100	100	100	100	100	100	100	100	100	100	100	100	101.016
Percentage of foreign material	13	17	29	20	22	13	9	13	13	13½	15⅔	19	12⅔	6	12.78

TABLE H.—*Darien terminal moraine of the Delavan lobe.*

Number of analysis	1	2	3	4	5	6	7	8	9	10
Town	Whitewater (T. 4 N., R. 15 E.).		Sugar Creek (T. 3 N., R. 16 E.).			Richmond (T. 3 N., R. 15 E.).				
Section	36	36	6	7	7	1	10	15	15	26
Fraction	SE. ¼	S. ½	N. ½	Mid.	W. ½	SW. ¼	SE. ¼	NW. ¼	E. ½	SW. ¼
Niagara limestone	68	59	59½	65⅔	64½	62	30	51	41	59
Galena limestone	7½	13	13¾	13⅓	19	11	39	18	24	11
Trenton limestone	4	5	2¼	2⅓	2½	4	7	2	12	6
St. Peter and Potsdam sandstone	.....	1	1	1⅓	.....	2	.....	2	.....	.....
Huronian quartzite	.....	.....	.....	.....	.....	.....	1	1	1	2
Archean crystalline rocks	13	17	18½	14	12½	14	14	22	10	20
Chert and quartz	.....	.....	1¼	.....	.....	.....	.....	1	2	.....
Doubtful, mostly limestone	6	1	3½	3	1½	1	9	3	7	2
Proof	100	100	100	100	100	100	100	100	100	100
Percentage of foreign material	13	17	18½	14	12½	14	14	22	10	22

TABLE H.—*Darien terminal moraine of the Delavan lobe*—Continued.

Number of analysis	11	12	13	14	15	16	17	18	19
Town	Darien (T. 2 N., R. 15 E.)								Delavan (T. 2 N., R. 16 E.).
Section	2	10	13	15	22	24	26	36	30
Fraction	E. ½	SW. ¼	NW. ¼	S. ½	W. ½	SE. ¼	NW. ¼	SE. ¼	SW. ¼
Niagara limestone	51	57	38	46	48	47	51	55	56
Galena limestone	17	10	16	20	16	18	9	16	14
Trenton limestone	9	13	21	14	10	19	12	15	15
St. Peter and Potsdam sandstone	......	3	1	1	1	......	2	......	2
Huronian quartzite	......	......	......	......	......	......	......	......	......
Archean crystalline rocks	15	13	18	15	18	14	17	12	9
Chert and quartz	......	1	......	......	......	1	......	......	1
Doubtful, mostly limestone	8	3	6	4	7	1	9	2	3
Proof	100	100	100	100	100	100	100	100	100
Percentage of foreign material	5	16	19	16	19	14	19	12	11

Number of analysis	20	21	22	23	24	25	26	27	28	29	Averages (Galena and Trenton, approximate).
Town	Walworth (T. 1 N., R. 16 E.).				Bloomfield (T. 1 N., R. 18 E.)					Lyons (T. 2 N., R. 18 E.).	
Section	16	15	22	25	20	8	6	5	3	24	
Fraction	NW. ¼	NE. ¼	N. ½	Mid.	W. ½	SE. ¼	SE. ¼	W. ½	W. ½	SW. ¼	
Niagara limestone	56	57	62	71	86⅔	80½	79⅔	80	90	82¾	60.69
Galena limestone	19	......	} 26	......	......	......	......	......	......	......	12.24
Trenton limestone	......	......	......	......	......	......	......	......	......	......	6.33
St. Peter and Potsdam sandstone	2	3	......	......	⅓	......	⅓	⅓	......	¼	0.86
Huronian quartzite	1	......	......	......	......	½	⅔	½	⅓	¼	0.278
Archean crystalline rocks	19	15	12	12	13	19	19⅓	19⅓	9⅓	16	14.82
Chert and quartz	......	......	......	......	......	......	......	......	......	......	0.27+
Doubtful, mostly limestone	3	25	......	17	......	......	......	......	⅓	¾	4.32
Proof	100	100	100	100	100	100	100	100	100	100	99.818
Percentage of foreign material	22	18	12	12	13½	19½	20⅓	20	9⅔	16½	15.74

TABLE I.—*Elkhorn terminal moraine of the Delavan lobe.*

Number of analysis	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Town	Palmyra (T. 5 N., R. 16 E.).		Troy (T. 4 N., R. 17 E.).	Lagrange (T. 4 N., R. 16 E.).				Lafayette (T. 3 N., R. 17 E.).	Sugar Creek (T. 3 N., R. 16 E.).					
Section	35	36	6	14	24	26	29	7	10	14	16	21	34	31
Fraction	N. ½	SW. ¼	S. ½	SE. ¼	S. ½	NW. ¼	E. ½	S. ½	NE. ¼	S. ½	W. ½	S. ½	N. ¼	S. ½
Niagara limestone	56	65	65½	56½	63	69	53½	71	58½	72	70½	56	58	51
Galena limestone	21	15	11	12	7	13	7	5	14½	7	13	6	11	11
Trenton limestone	......	......	4	......	......	......	17½	12	½	......	......	15	11	17
Lower Magnesian limestone (including Mendota limestone)	......	......	......	......	......	......	......	......	......	......	......	......	......	......
St. Peter and Potsdam sandstone	......	......	2	2	4	......	3	1	1	1	1	......	......	3
Huronian quartzite	......	......	......	......	......	......	......	......	1	......	......	......	......	......
Archean crystalline rocks	23	17	14½	24½	24	11	18½	10	22½	13	12	19	18	14
Chert and quartz	......	......	½	......	......	......	½	......	......	......	......	2	......	......
Doubtful, mostly limestone	......	3	3½	3	2	7	......	1	2	7	3½	2	1	4
Proof	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Percentage of foreign material	23	17	14½	24½	24	11	18½	10	22½	13	12	19	18	17

Number of analysis	15	16	17	18	19	20	21	22	23	24	25	26	27	Averages (Galena and Trenton approximate).
Town	Delavan (T. 2 N., R. 16 E.)							Geneva (T. 2 N., R. 17 E.).		Lyons (T. 2 N., R. 18 E.).		Burlington (T. 2 N., T. 3 N., R. 19 E.).		
Section	7	8	8	9	21	3	14	29	24	17	10	6	31	
Fraction	E. ½	NW. ¼	SW. ¼	NW. ¼	S. ½	S. ½	SE. ¼	NW. ¼	N. ½	NW. ¼	SE. ¼	NW. ¼	NW. ¼	
Niagara limestone	59	45	53	47	75	54	51	74	77	59	80⅕	82⅖	86⅕	64.05
Galena limestone	7	12	11	11	2	11	15	......	11	......	......	......	......	7.64
Trenton limestone	15	11	12	17	8	18	9	......	......	1	......	......	......	7.49
Lower Magnesian limestone (including Mendota limestone)	......	......	......	......	......	......	......	......	......	......	......	......	......	......
St. Peter and Potsdam sandstone	2	2	1	4	1	......	2	......	......	......	⅗	⅘	......	1.20
Huronian quartzite	......	......	......	......	......	......	......	......	1	5	⅖	⅕	......	.28
Archean crystalline rocks	16	26	18	17	12	17	20	12	7	15	17⅘	16⅕	13⅘	16.62
Chert and quartz	......	......	......	......	......	......	......	......	......	......	⅕	⅖	......	.13
Doubtful, mostly limestone	1	4	5	4	2	......	3	14	4	20	⅘	......	......	3.65
Proof	100	100	100	100	100	100	100	100	100	100	100	100	100	101.06
Percentage of foreign material	18	28	19	21	13	17	22	12	8	20	18⅗	17⅕	13⅘	17.46

TABLE J.—*Valparaiso terminal morainic system.*

Number of analysis	1	2	3	4	5	6	7	8	9	10	11
Town	Genesee (T. 6 N., R. 18 E.).	New Berlin (T. 6 N., R. 20 E.).			Muskego (T. 5 N., R. 20 E.).			Waterford (T. 4 N., R. 19 E.).			
Section	35	29	31	32	5	8	9	27	34	35	35
Fraction	......	SE. 1/4	SE. 1/4	SW. 1/4	Mid.	NE. 1/4	SE. 1/4	SW. 1/4	NE. 1/4	NW. 1/4	NE. 1/4
Niagara limestone	86 2/3	82.4	89.5	86	88.1	89.4	92.3	89.5	82.7	91	86.2
Galena limestone	......	......	......	......	......	......	......	......	......	......	......
Trenton limestone	......	......	......	......	......	......	......	......	......	......	......
Lower Magnesian limestone (including Mendota limestone)	......	......	......	......	......	......	......	......	......	......	......
St. Peter and Potsdam sandstone	1/3	.5	.8	1/3	.2	.1	.2	......	.6	......	.1
Huronian quartzite	......	......	......	......	.1	......	.1	......	1.4	......	......
Archean crystalline rocks	13	17.1	9.7	13 2/3	11.6	10.5	6.9	10.5	15.3	9	13.7
Chert and quartz	......	......	......	......	......	......	......	......	......	......	......
Doubtful, mostly limestone	......	......	......	......	......	......	.2	......	......	......	......
Proof	100	100	100	100	100	100	100	100	100	100	100
Percentage of foreign material	13 1/3	17.6	10.5	14	11.9	10.6	7.2	10.5	17.3	9	13.8

Number of analysis	12	13	14	15	16	17	18	19	20	Averages.
Town	Rochester (T. 12 N., R. 13 E.).		Burlington (T. 3 N., T. 2 N., R. 19 E.).				Brighton (T. 2 N., R. 20 E.).	Salem (T. 1 N., R. 20 E.).	Randall (T. 1 N., R. 19 E.).	
Section	13	18	29	5	4	15	19	20	20	
Fraction	NW. 1/4	NW. 1/4	SW. 1/4	NW. 1/4	SW. 1/4	SE. 1/4	N. 1/2	SW. 1/4	SW. 1/4	
Niagara limestone	87 2/3	84 1/4	83	84	83 2/3	91	88 3/8	83 1/5	84 1/3	86.724
Galena limestone	......	......	......	......	......	......	......	......	......	......
Trenton limestone	......	......	......	......	......	......	......	......	......	......
Lower Magnesian limestone (including Mendota limestone)	......	......	......	......	......	......	......	......	......	......
St. Peter and Potsdam sandstone	......	1/2	......	5/7	2/3	1/3	1/8	1	2/3	.365
Huronian quartzite	......	1/4	1/4	1/7	......	1/3	1	1/10	......	.184
Archean crystalline rocks	12 1/3	14 3/4	16 3/4	14 5/7	15 2/3	8	10 1/2	14 4/5	15	12.71
Chert and quartz	......	......	......	2/7	......	1/3	......	3/10	......	.003
Doubtful, mostly limestone	......	......	......	1/7	......	......	......	......	......	.005
Proof	100	100	100	100	100	100	100	100	100	99.991
Percentage of foreign material	12 1/3	15.5	17	15 4/7	16 1/3	8 2/3	11 5/8	15.9	15 2/3	13.259

TABLE K.—*Lake-border morainic system.*

Number of analysis	1	2	3	4	5	6	Averages.
Town	Lake (T. 6 N., R. 21 E.).	Greenfield (T. 6 N., R. 21 E.).	New Berlin (T. 6 N., R. 20 E.).	Muskego (T. 5 N., R. 20 E.).	Franklin (T. 5 N., R. 21 E.).		
Section	7	32	36	12	7	35	
Fraction	NW. 1/4	SW. 1/4	SW. 1/4	SE. 1/4	NE. 1/4	N. 1/2	
Hamilton limestone and shale	11 1/5	5/8	....	1/2	....	9 1/5	3.62
Salina formation	18 1/5	1 2/5	....	2 1/2	5/10	9 2/5	5.41
Niagara limestone	49 3/5	81 4/5	90 1/5	81 2/5	92 1/2	64	76.63
Galena limestone	....	....	....	....	....	....	....
Trenton limestone	....	....	....	....	....	....	....
Lower Magnesian limestone	....	....	....	....	....	....	....
St. Peter and Potsdam sandstone	3/5	5/6	2/5	2/5	1/2	1 2/5	.81
Huronian quartzite	1/5	....	....	1/2	....	....	.116
Archean crystalline rocks	16 3/5	15	9	14 1/6	6 1/2	15 1/5	12.76
Chert and quartz	....	....	....	....	....	....	....
Doubtful, mostly limestone	3 4/5	....	....	....	....	....	.63
Proof	100	100	100	100	100	100	99.99
Percentage of foreign material	17 2/5	15 5/6	9 2/5	15 1/5	7	17	13.70

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