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THE PLEISTOCENE OF INDIANA AND MICHIGAN AND THE HISTORY OF THE GREAT LAKES

BY
FRANK LEVERETT
AND
FRANK B. TAYLOR

WASHINGTON
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ABSTRACT OF VOLUME.

This monograph describes the glacial features and the great glacial lakes of a district in Indiana and Michigan lying between the areas covered by Monographs XXXVIII[1] and XLI.[2] The glacial features are treated mainly by Mr. Leverett, and the glacial lakes and their moraines by Mr. Taylor. The pre-Wisconsin glacial and interglacial formations are given attention, but the principal subject of discussion is the Wisconsin drift of the Saginaw lobe and the neighboring portions of the Lake Michigan and Huron-Erie lobes.

CHAPTER I. INTRODUCTION.—The drift sheets and intervals are outlined and the time divisions of stage and substage are explained. A bibliography of about 400 papers by nearly 150 different authors dealing with the region of the Great Lakes and the area southward to the Ohio is given.

CHAPTER II. PHYSICAL FEATURES.—The altitude and relief, the principal topographic features, the drift topography, the drainage systems, and the thickness of drift are briefly treated. The region is one of only moderate relief and the altitude nowhere reaches 2,000 feet. Small areas in the basins of Lakes Michigan and Huron are below sea level.

CHAPTER III. PRE-WISCONSIN DRIFT AND ASSOCIATED DEPOSITS.—The limits of glaciation in Indiana and Kentucky are outlined. The question of pre-Illinoian drift is discussed but no conclusion is reached. The topography, structure, and rock constituents, and other deposits of the pre-Wisconsin drift are briefly discussed. The striæ outside the Wisconsin drift are tabulated. The Sangamon soil and the post-Sangamon or main loess are briefly discussed.

CHAPTER IV. THE WISCONSIN DRIFT BORDER.—The edge of the Wisconsin drift and its characteristics are the main theme, but the existence of an earlier and a later Wisconsin drift and the grouping of moraines are treated briefly.

CHAPTER V. CORRELATIVES OF THE CHAMPAIGN MORAINIC SYSTEM.—The correlation of the Champaign moraines differs somewhat from that given in Monograph XXXVIII; moraines which were there said to override the Champaign system in western Indiana are now considered to be probable correlatives of that system.

CHAPTER VI. CORRELATIVES OF THE BLOOMINGTON MORAINIC SYSTEM.—The Bloomington morainic system of the Lake Michigan lobe is interpreted as finding its continuation across Indiana in a great belt of thick drift which runs eastward from Benton and Warren counties, with a slight bowing to the southward in central Indiana, and which enters Ohio from Randolph and Wayne counties. It is continued in Ohio as the “Main morainic system” discussed in Monograph XLI.

CHAPTER VII. THE SAGINAW LOBE.—The change from undifferentiated drift to definite lobes is interpreted as having been caused by a great recession of the border

in the district east of the Lake Michigan lobe in northern Indiana and southern Michigan. Several moraines lying in this area of recession are discussed.

CHAPTER VIII. MORAINES OF THE NORTHERN LIMB OF THE HURON-ERIE LOBE IN INDIANA.—A complex morainic system is described as running northeastward from near Delphi, Ind., to the northeast corner of the State. It is interpreted as the correlative of several moraines that lie between it and the Lake Michigan lobe.

[1]Leverett, Frank, The Illinois glacial lobe: Mon. U. S. Geol. Survey, vol. 38, 1899.

[2]Leverett, Frank, Glacial formations and drainage features of the Erie and Ohio basins: Mon. U. S. Geol. Survey, vol. 41, 1902.

CHAPTER IX. MORAINIC SYSTEMS AT HEADS OF LAKE MICHIGAN AND SAGINAW BASINS.—The Kalamazoo morainic system of the Lake Michigan lobe; which was referred in Monograph XXXVIII to ice on its eastern side, is now interpreted as a product of the Lake Michigan lobe and distinct from the Valparaiso morainic system from South Bend, Ind., northeastward into Michigan though apparently merged with it in northwestern Indiana. The Lake Michigan-Saginaw interlobate tract, a prominent belt of interlobate moraines and included gravel plains, is described as running northward from Kalamazoo County to the vicinity of Cadillac. A strong morainic system of the Saginaw lobe, a continuation of the Kalamazoo morainic system, is described as running eastward from Barry County across Calhoun and Jackson counties to western Washtenaw County; its outer border shows great outwash aprons and lines of vigorous glacial drainage. The conspicuous moraines of the interlocking Saginaw and Huron-Erie lobes in southeastern Michigan and the included outwash plains and glacial drainage lines on the prominent peninsula known as the " thumb" of Michigan are described as far northeast as southern Lapeer County. The Charlotte morainic system of the Saginaw lobe is interpreted as a close successor of the Kalamazoo system and in places as being nearly merged with it. The Valparaiso morainic system of the Lake Michigan lobe is interpreted as a probably nearly full correlative of the Charlotte morainic system and a close successor of the Kalamazoo morainic system. It sweeps around the head of Lake Michigan in great strength.

CHAPTER X. LATER MORAINES OF THE LAKE MICHIGAN, SAGINAW, AND HURON-ERIE LOBES.—The Lake-Border morainic system of the Lake Michigan lobe, a series of slender moraines in the south part of the Lake Michigan basin between the Valparaiso morainic system and the shore of Lake Michigan and their continuation north and east over the highlands of the northern part of the southern peninsula of Michigan, is discussed. The reentrant district between the Lake Michigan and Saginaw lobes is declared to contain several narrow but well-defined moraines, which bow out to the northeast and become more convex in passing from older to younger. The moraines of the western limb of the Saginaw lobe, a massive morainic system northwest of Saginaw Bay, are described as separating into several distinct moraines southward, in the vicinity of Grand River. The moraines of the eastern limb of the Saginaw lobe, a series of slender moraines running from Grand River in Ionia County eastward and northward to Tuscola County, are described and the accompanying glacial drainages are discussed. The "thumb" of Michigan is interpreted as an interlobate area in which the slender moraines of the eastern limb of the Saginaw lobe become interlocked with moraines of the Huron-Erie lobe. Some of the later moraines of the Huron-Erie slope in southeastern Michigan are interpreted as having been laid down in glacial lake waters and to have very faint expression. The correlatives of the West Branch-Gladwin group of moraines in Ohio, New York, and Ontario and the Detroit interlobate moraine in southwestern Ontario are discussed very briefly.

CHAPTER XI. PORT HURON MORAINIC SYSTEM AND PROBABLE CORRELATIVES.—In the Huron and Saginaw basins the Port Huron morainic system is interpreted as marking a pronounced readvance of the ice border and is definitely correlated with glacial Lake Whittlesey; it is described as consisting of several closely associated ridges to which individual names have not been applied. The probable correlatives of the Port Huron system in Ontario and New York are briefly discussed. In the northern Michigan and northern Huron basins a morainic belt marking a distinct readvance of the ice in the northern portion of the Michigan basin is interpreted as the correlative of the Port Huron system; studies by Alden on the west side of Lake Michigan are declared to have brought out evidence of a readvance there. Other glacial features in the area between the Port Huron morainic system and the shores of Lakes Michigan and Huron are briefly discussed. Drumlins are conspicuous in the Grand Traverse region and occur in small areas east of Mullet Lake and near Alpena. Striæ harmonize in trend with the drumlins of Alpena County. Overridden lake (?) clays occur in the Grand Traverse region at elevations not greater than about 300 feet above Lake Michigan on the borders of deep and narrow lowlands largely occupied by lakes.

CHAPTER XII. OUTLINE OF GLACIAL AND POSTGLACIAL HISTORY OF THE GREAT LAKES REGION.—A brief outline of the Great Lakes history during and after the recession of the last ice sheet is given.

CHAPTER XIII. GLACIAL LAKE MAUMEE.—Glacial Lake Maumee, the oldest of the glacial lakes in the Huron-Erie basin, is said to have enlarged and contracted in area with the recession and readvance of the ice border and to have shifted its outlet from Fort Wayne, Ind., to Imlay, Mich. The beaches of the south shore are described as having been apparently greatly disturbed by winter ice that grounded and shoved the shore material into ramparts back of the original shore line. Ice attraction is also briefly discussed,

CHAPTER XIV. GLACIAL LAKE CHICAGO.—The three beaches of the southern part of the eastern shore of Lake Michigan, formed by a lake discharging southwestward to the Illinois River, are briefly described.

CHAPTER XV. GLACIAL LAKE SAGINAW.—A lake formed in the Saginaw basin outside the oscillating ice border is said to have varied considerably in area and yet to have discharged southwestward continuously through the Grand River outlet to Lake Chicago.

CHAPTER XVI. GLACIAL LAKE ARKONA.—A lake that covered much of the area of Lake Maumee and Lake Saginaw and discharged into the Grand River outlet is described.

CHAPTER XVII. GLACIAL LAKE WHITTLESEY.—Lake Arkona is interpreted as having beer, so encroached on by a readvance of the ice border on the "Thumb" of Michigan that it was separated into two bodies of water, that to the east being called Lake Whittlesey and that to the west the Second Lake Saginaw; Lake Whittlesey discharged by the Ubly outlet to the Second Lake Saginaw and thence to the Grand River outlet and Lake Chicago.

CHAPTER XVIII. GLACIAL LAKE WAYNE.—The ice border is described as having receded sufficiently after its readvance to the main moraine of the Port Huron system to permit eastward discharge past Syracuse, N. Y., when the lake was drawn down to the level of the Wayne beach of southeastern Michigan.

CHAPTER XIX. GLACIAL LAKE WARREN.—The outlets of Lake Wayne past Syracuse are interpreted as having been covered by a readvance of the ice by which the glacial Jake was raised high enough to discharge westward through the Grand River outlet, though at a level slightly below that of Lake Arkona. The name Lake Warren is applied to this expanded body of water.

CHAPTER XX. GLACIAL LAKE LUNDY AND THE TRANSITION TO LAKE ALGONQUIN.—With the recession of the ice border, discharge eastward is said to have been resumed, probably at first by way of the Syracuse channels. But later, by the opening of the Mohawk Valley through ice recession, the lake was drawn down to the level of the Niagara escarpment in the Erie basin and still lower in the Ontario basin. Niagara Falls then came into operation, and the Erie basin held a small lake which received the discharge from a glacial lake in the southern part of the Huron basin, the Early Lake Algonquin. Lake Chicago still persisted as an independent lake in the Michigan basin and Lake Duluth in the Superior basin.

CHAPTER XXI. GLACIAL LAKE ALGONQUIN.—By the opening of the low passage from the Michigan to the Huron basin Lake Chicago is interpreted as having become confluent with the Early Lake Algonquin. With further recession of the ice the Superior waters were also admitted and the great glacial Lake Algonquin resulted. By the uncovering of the Trent Valley in Ontario the discharge through the St. Clair Valley was abandoned, the Trent being the lower. Eventually differential uplift carried the Trent outlet above the level of the St. Clair, and the discharge returned to the St. Clair outlet and remained there during much of the time of rapid differential uplift. In connection with Lake Algonquin the contemporary lakes in the St. Clair and Erie basins are briefly treated.

CHAPTER XXII. THE NIPISSING GREAT LAKES.—The withdrawal of the ice is described as having opened the low passage to the Ottawa Valley. Eastward discharge along the south slope probably began while the ice was still present in the valley. The Nipissing Great Lakes stage dated from the complete opening of this valley and continued to the time when northward uplift had brought the outlet up past the level of the St. Clair outlet and had caused a return to the discharge through the St. Clair Valley. There appears to have been a long two-outlet stage during which the beach known as the Nipissing was formed. The earlier beach, formed during the operation of the Ottawa outlet alone, became submerged and effaced by the rising waters everywhere in this lake area south of an isobase running through the head of the outlet.

CHAPTER XXIII. POST-NIPISSING GREAT LAKES AND SUMMARY OF GLACIAL AND NON-GLACIAL LAKES.—Beaches between the Nipissing and modern beaches, correlative post-Nipissing lakes in the Erie and Ontario basins, and the Champlain Sea are discussed. The problem of recent and progressing earth movement is considered briefly.

CHAPTER XXIV. POSTGLACIAL DEVELOPMENT OF CONNECTING RIVERS OF THE GREAT LAKES.—The history of St. Clair and Detroit rivers is given in some detail and that of the other rivers is briefly outlined.

CHAPTER XXV. DEFORMATION OF THE SHORE LINES.—The probable influence of ice attraction and the resilience following depression by ice weighting are discussed. Tectonic earth movements and negative eustatic and oceanic oscillatory movements are briefly considered.

CHAPTER XXVI. ECONOMIC RESOURCES.—Marl, peat, clay, and other materials of commercial value, underground water supplies, and the agricultural values of the soils of the region are briefly treated. References are made to detailed descriptions published elsewhere.

CHAPTER I.
INTRODUCTION.

By FRANK LEVERETT.

OUTLINE OF AREA AND SUBJECTS OF DISCUSSION.

The area discussed in this monograph lies between that discussed in Monograph XXXVIII (The Illinois glacial lobe) and that in Monograph XLI (The glacial formations and drainage features of the Erie and Ohio basins). It includes a considerable part of Indiana and all of the southern peninsula of Michigan. The monographs referred to contain a discussion of the entire exposed portion of the Illinoian drift in Indiana as well as in the neighboring States on the east and the west. The question of a pre-Illinoian drift in southern Indiana arose subsequently through studies in 1902 and is briefly treated in the present paper, but the Wisconsin drift, the concealed portions of the earlier drift sheets that underlie it, and the somewhat intricate lake history associated with and following the retreat of the ice are the main subjects of discussion.

FIELD WORK.

The Wisconsin and underlying drifts have been investigated chiefly by Mr. Leverett, and the lake history has been worked out largely by Mr. Taylor. During the investigations in Michigan, however, field conferences were frequent, so that each author is in a measure familiar with the main features and problems discussed by the other. Mr. Taylor's work in the neighboring portion of Canada, some results of which are presented, was carried on largely at private expense prior to his connection with this Survey. It was continued under the auspices of the Canadian Survey in 1908, 1909, 1911, and 1912.

The work of Mr. Leverett in Indiana and Michigan and that of Mr. Taylor in Michigan has been prosecuted chiefly under the direction of Prof. T. C. Chamberlin, who by his active interest, helpful suggestions, and occasional field visits has greatly stimulated the work and aided in the interpretation.

Dr. A. C. Lane, as State geologist, cooperated in the work in Michigan by helpful suggestions and contribution of valuable data which had come into his possession. He also, through an arrangement with the United States Geological Survey, contributed to the work from the State funds on the understanding that the State Survey should receive special reports on areas investigated by the aid of such funds. Through this arrangement Lapeer County was studied and described by Mr. Taylor in 1900, and Alcona County by Mr. Leverett in 1901. In addition to this the members of the State Survey have studied in some detail the Pleistocene features of Arenac, Bay, Huron, Iosco, Kent, Monroe, Saginaw, Sanilac, Tuscola, and Wayne counties with results that appear in the State reports. The work in these counties was so thorough that only a review was needed to connect it fully with the work in the bordering counties.

The annual reports of the Indiana Geological Survey contain results of somewhat detailed studies of the glacial deposits of certain counties and general observations on the drift of the remainder of the State. Those by C. R. Dryer present exceptionally clear descriptions of the several moraines of the northeastern counties. These and other contributions by the Indiana Survey are reviewed in connection with the discussion of features on which they have bearing. The work of the Indiana Survey under the State geologist, W. S. Blatchley, has been directed toward the investigation of certain commercial products and, except in the report on road materials issued in 1906, has been little concerned with the glacial deposits.

As reference to townships is commonly made by number and range rather than by civil names, and as the numbering is connected with more than one meridian and base line, a brief explanation of the system is given.

Most of the townships of Indiana are numbered east and west from the second principal meridian, which runs through the State about 86° 28; W. from Greenwich. A small triangular area in the southeast part of the State, however, is numbered west from the first principal meridian, which follows the State line of Indiana and Ohio. All the townships are numbered north and south from a base line that crosses the southern portion of the State 1 to 2 miles south of latitude 38° 30' N. The State extends from T. 9 S. to T. 38 N. of this base line.

The townships of Michigan are numbered east and west from the Michigan meridian, which leads from Sault Ste. Marie south to the Ohio State line, and north and south from a base line that follows the parallel 42° 30'. The State extends from T. 8 S. to T. 39 N. in the southern peninsula and to T. 66 N. on Isle Royal in Lake Superior.

Each township has 36 sections numbered back and forth in tiers of six, the numbering beginning at the northeast and ending at the southeast corner of the township.

GLACIAL GATHERING GROUNDS AND ICE LOBES.

Studies by the Canadian Geological Survey have brought to light several large gathering grounds with smaller gathering grounds on their peripheries. The larger ice fields have been named from their places of occurrence, the Cordilleran, the Keewatin, the Patrician, and the Labrador. The Cordilleran field at its maximum occupied much of Canada west of the Rocky Mountains, but did not extend far south into the United States. The Keewatin field occupied central Canada, extended southward into the United States across Minnesota, the Dakotas, Iowa, and Nebraska into southeastern Kansas and central Missouri, and encroached on western Wisconsin and western Illinois. The Patrician[1] lay between Hudson Bay and Lake Superior and may have

extended over Michigan. The Labrador ice field extended from the Labrador Peninsula southward and southwestward to the limits of glaciation in the district between the Atlantic seaboard and the Mississippi Valley; it encroached slightly on southeastern Iowa and caused a temporary displacement[2] of the part of Mississippi River touching eastern and southeastern Iowa. It is with the Labrador ice field that the present monograph is chiefly concerned, and with that part of it which covered the southern peninsula of Michigan and the glaciated portion of Indiana. As indicated later (pp. 64-65) the Patrician ice field may prove to have spread southeastward across Michigan into Indiana and Ohio before the Labrador ice field had entered this region.

The Labrador ice field developed two large lobes west of the Appalachians in its extension beyond the great basins through which it passed. The western lobe spread from the Lake Michigan basin over much of Illinois, forming the Illinois glacial lobe, the theme of Monograph XXXVIII. Its neighbor on the east extended through the Huron-Erie basin and on across western Ohio and eastern Indiana to the edge of Kentucky, forming another large glacial lobe. Between these two great lobes there is a conspicuous reentrant angle in the glacial boundary in southern Indiana. East of the eastern lobe there is a reentrant on the west slope of the Alleghenies which extends as far north as western New York. East of the Alleghenies there was less extensive lobing, though the border of the ice conformed markedly to the marginal topography.

[1]Tyrrell, J. B., Hudson Bay exploring expedition, 1912: Twenty-second Ann. Rept. Ontario Bur. Mines, pt. 1, 1913.

[2]Mon. U. S. Geol. Survey, vol. 38, 1899, p. 89.

The two great lobes mentioned were best developed at the time of maximum extent of the Labrador ice field, and this apparently occurred at the Illinoian stage of glaciation. At a later stage, the Wisconsin, there were two distinct lobes, the Green Bay and the Lake Michigan, in the western portion of the district covered by the Labrador ice field, and several lobes, the Saginaw, Maumee, East White, Miami, Scioto, and Grand River, within the limits of the eastern or Indiana-Ohio portion. These lobes blended somewhat at the culmination of Wisconsin glaciation.

The district considered in this monograph includes portions of the Illinois lobe and of the Indiana-Ohio lobe of the Illinoian ice invasion, and the entire Saginaw, Wabash, and East White lobes and the eastern portion of the Lake Michigan lobe of the Wisconsin ice invasion. This lobation, as long since suggested by Chamberlin,[1] resulted in great degree from the rapid movement and protrusion of the ice in tracts of low altitude. The overlapping of the Labrador ice on ground previously occupied by the western Ice indicates a marked change, the cause for which is not yet clearly understood, in the conditions for ice accumulation in the two gathering grounds.

GLACIAL SUCCESSION.

The occurrence of several distinct sheets of drift separated by soils and iron-stained, leached, or weathered surfaces has been recognized for some years by those familiar with the glacial deposits of North America. The matter has been discussed by the present writer at some length in each of the two monographs already published,[2] and for this reason only a brief outline is here presented. In order of age from older to younger the following drift sheets and intervals appear:

OLDEST RECOGNIZED DRIFT.

In New Jersey and eastern Pennsylvania an old drift, named by Chamberlin and Salisbury[3] the Jerseyan and considered by them as old as any yet found in America, is preserved chiefly in places where erosion has been at a minimum and over much of the area is now present only in small detached patches. It is very deeply weathered, a fact that corroborates the testimony of erosion as to its great age.

In northwestern Pennsylvania on the borders of the Allegheny Valley an old drift, preserved in the recesses of bluffs and in scanty deposits on uplands, seems scarcely so old as the Jerseyan and yet may prove to be its correlative.

West of the Mississippi an extensive sheet of old drift pertaining to the Keewatin ice field is covered by the Kansan drift and thus has received the name pre-Kansan. It lies also beneath the Aftonian buried soil and weathered zone and for that reason is frequently referred to as the sub-Aftonian drift. Recently Prof. Shimek, of the Iowa Geological Survey, traced it westward into Nebraska and gave it an additional name, the Nebraskan. This drift is separated from the Kansan by the long interglacial Aftonian stage and is much the older, old though the Kansan is, and it is thought to be a possible if not a probable correlative of the Jerseyan drift. It is still, however, not definitely settled that the Labrador and Keewatin ice fields reached the limits of these their oldest drift sheets contemporaneously.

G. M. Dawson[4] applied the term Albertan to a deposit of mountain drift and gravel in the Province of Alberta in Canada and in neighboring parts of Montana which he considered to be derived from the Rocky Mountain ice. Later investigations by Calhoun[5] raising doubts as to the glacial origin of this gravel have been negatived by W. C. Alden, who in 1911 and 1912 discovered glaciated pebbles and distinct evidence of glacial origin.[6] The aspect of the deposit is very aged and at present it is considered an early glacial deposit.

[1]Trans. Wisconsin Acad. Sci., vol. 4, 1878, pp. 201-234; Third Ann. Rept. U. S. Geol. Survey, 1883, pp. 291-402.

[2]The Illinois glacial lobe: Mon. U. S. Geol. Survey, vol. 38, 1899; Glacial formations and drainage features of the Erie and Ohio basins: Mon. U. S. Geol. Survey, vol. 41, 1902.

[3]Geology, vol. 3, 1904, pp. 383-384.

[4]Glacial deposits of southwestern Alberta: Bull. Geol. Soc. America, vol. 7, 1895, pp. 31-66.

[5]Calhoun, F. H. H., The Montana lobe of the Keewatin ice sheet: Prof. Paper U. S. Geol. Survey No. 50, 1906, pp. 42-52.

[6]Pre-Wisconsin glacial drift in the region of Glacier National Park: Bull. Geol. Soc. America, vol. 23, 1912, pp. 687-708.

It is an open question whether the oldest drift is represented in the southern peninsula of Michigan and in Indiana, the area covered by the present report. The presence of copper nuggets in the drift over the entire southern peninsula and southeastward into central Ohio seems to call for an ice movement from the Lake Superior region across the southern peninsula and probably through the Huron basin to the limits reached by the nuggets. The ice movement in the Illinoian and Wisconsin stages of glaciation seems to have been such that copper could not have been carried into Ohio from the Lake Superior region. It appears, therefore, that this transportation was effected in Kansan time or earlier, at a time when the Labrador glaciation was relatively weak.

FIRST OR AFTONIAN INTERGLACIAL STAGE.

Evidence of the Aftonian interglacial stage is clearest in the region west of the Mississippi. It was noted about 1888 by Chamberlin and McGee near Afton, Iowa, and was made by Chamberlin[1] the type locality for the interval. Bain[2] subsequently brought out additional data concerning it. Calvin[3] and Shimek[4] have recently presented results of studies in western Iowa which give a clearer understanding of this deglaciation interval and which make it appear that a warm temperate fauna had possession of that region between the pre-Kansan and Kansan stages of glaciation.

KANSAN DRIFT.

The Kansan drift, which in the Mississippi Valley overlies the pre-Kansan drift and which is thought to extend beyond its limits in Kansas and Missouri, was first clearly brought to notice in its proper relations by Calvin and his associates on the Iowa Geological Survey and is discussed in the several volumes of that survey which deal with counties of eastern, southern, and western Iowa. It is an open question whether this drift is represented in southern Michigan and Indiana. Possibly the copper noted above was brought in at this instead of pre-Kansan time. As a surface sheet the Kansan is displayed in the States west of the Mississippi, though even there it is covered by loess. It is also overridden to some extent near the Mississippi by the Illinoian drift.

SECOND OR YARMOUTH INTERGLACIAL STAGE.

SOIL AND WEATHERED ZONE.

The first part of the second interglacial stage embraces a long interval, during which the surface of the Kansan drift was weathered and the soil and peat beds which separate the Kansan from the overlapping Illinoian drift were developed. The region of overlap is along the borders of the Mississippi south of the driftless area, in southeastern Iowa and western Illinois. The locality where evidence of this interval was first clearly recognized is at Yarmouth (near Burlington), Iowa, where the overlap is by the drift of the Labrador ice field upon that of the Keewatin ice field.

LOESS.

Between the Yarmouth interglacial soil and weathered drift and the overlying Illinoian drift, and therefore of pre-Illinoian age, there lies in places a deposit of loess, which is best displayed in the region of overlap of the Illinoian on the Kansan drift, and which seems to have resulted from a less humid climate than that under which the peat was formed.

[1]Classification of American glacial deposits: Jour. Geology, vol. 3, 1895, p. 272.

[2]Bain, H. F., Proc. Iowa Acad. Sci., vol. 5, 1898, pp. 86-101.

[3]Calvin, Samuel, Proc. Davenport Acad. Sci., vol. 10, 1907, pp. 18-31, 7 pls.; Bull. Geol. Soc. America, vol. 20, 1909, pp. 136-139, 341-356.

[4]Shimek, Bohumil, Bull. Geol. Soc. America, vol. 20, 1909, pp. 399-408, Pls. XXX-XXXVII; vol. 21, 1910, pp. 119-140.

ILLINOIAN AND IOWAN DRIFTS.

The Illinoian appears to be the most extensive drift sheet of the Labrador ice field. It is thought to extend to the glacial boundary in Indiana as well as in neighboring parts of Ohio, Kentucky, and Illinois. The name Illinoian is applied because of the wide exposure of this drift sheet in the State of Illinois. In its peripheral portion it shows complexity that is not as yet fully understood. Loess is interbedded to some extent with till, and silt thought to be of aqueous deposition fills many of the valleys. The loess may prove to be derived from pre-Illinoian loess gathered by the wind from districts outside and redeposited in such manner as to become interbedded with Illinoian till.

The presence or extent of the Illinoian drift in the Keewatin field remains to be determined. The only drift yet reported in that region to occur between the Kansan and Wisconsin drift is termed Iowan. That drift, however, has been placed by the Iowa Geological Survey either as a correlative or a close forerunner of the main or post-Sangamon loess.

THIRD OR SANGAMON INTERGLACIAL STAGE.

A well-defined interval of soil forming and leaching on the surface of the Illinoian drift came in prior to the deposition of the overlying loess. The soil formed is named from the Sangamon River basin in Illinois, where its occurrence was brought to notice by Worthen many years ago in reports of the State Survey. The soil and the weathering are well developed in Indiana and Ohio as well as in Illinois.

POST-SANGAMON OR MAIN LOESS (IOWAN?).

The chief loess deposit east of Mississippi River overlies the Sangamon soil. West of that stream it extends beyond the limits of the Illinoian drift and rests either on a soil developed on the surface of the Kansan drift or on an earlier loess (pre-Illinoian) that has a patchy preservation in that region. As noted above, it has been considered a somewhat close correlative or possibly close successor of the Iowan drift. So far as the region under discussion is concerned no Iowan drift has been recognized.

PEORIAN OR POSTLOESSIAL SOIL AND WEATHERED ZONE.

The post-Sangamon loess and its associated silts suffered some weathering before the Wisconsin ice invasion. Exposures of the loess beneath the Wisconsin drift near Peoria, Ill., in which the upper part of the loess is more weathered than the lower, have led to the use of the name Peorian to represent the pre-Wisconsin weathering, erosion, and general alteration of the loess.

WISCONSIN DRIFT.

LOCATION OF THE BORDER.

At the culmination of the last or Wisconsin ice invasion the outline of the border differed considerably from that at the culmination of the Illinoian invasion, falling short in places by more than 100 miles and extending beyond in other places. The portion in Illinois fell short the most. From Illinois eastward to central Ohio the borders gradually approach each other, and beyond central Ohio the Wisconsin border overlaps the Illinoian and in places extends beyond the Jerseyan drift. In the Green Bay lobe of Wisconsin the Wisconsin drift overlaps the border of the Illinoian and encroaches on what had been driftless area in the Illinoian stage of glaciation.

The drift border of the Wisconsin invasion is more lobed than that of the Illinoian, especially in Indiana and Ohio, where it includes the deposits of the East White, Miami, Scioto, and Grand River lobes. In Illinois the Wisconsin had but one pronounced lobe, the Lake Michigan, whose outline was rudely concentric with that of the Illinoian drift border. This lobe was an extension from the Lake Michigan basin. It formed, in the course of its withdrawal from Illinois, a succession of bulky but rather smooth morainic ridges, which extend into western Indiana for a few miles to the head of the reentrant between it and the portion of the Labrador ice field that passed through the Huron and Erie basins. This reentrant is a few miles farther west than the great reentrant between the Illinois and the Huron-Erie lobes of the Illinoian stage (see Pl. V, p. 62), the latter being in south-central rather than southwestern Indiana.

The moraines of the Huron-Erie lobe east of the reentrant differ in type from those formed by the Lake Michigan lobe on the west. They lack the strong bold ridges of the moraines of the Lake Michigan lobe and vary greatly in expression from place to place. A portion of pronounced morainic type with closely aggregated bowlder-strewn hummocks inclosing numerous basins may be followed within a few miles by a stretch where the knolls or hummocks are very scattered, and the whole aspect is vague. In places bowldery strips tie together well-defined sections, but in some places even these fail, leaving the ice border without definite trace. The bowldery belts also take singular turns away from the moraines, some of them in fact lying more nearly coincident with the direction of ice movement than with the trend of the ice border. This lack of continuity characterizes all the moraines of Wisconsin drift in Indiana outside the Mississinawa morainic system of the Huron-Erie lobe.[1] That system and later ones in the series formed by the Huron-Erie lobe, though less bulky than the moraines of the Lake Michigan lobe, are well-defined ridges that control the drainage and admit of easy tracing.

EARLIER AND LATER WISCONSIN.

The contrast between the features of the Lake Michigan lobe and those of the Huron-Erie lobe and especially the contrast in topography were at first thought to show a difference in age, the sharp hummocky shapes east of the reentrant angle being thought to be fresher than the gentle undulations of the drift of the Lake Michigan lobe west of it. This idea has been widely introduced into the literature and on it is based the division into earlier and later Wisconsin, the moraines of the Lake Michigan lobe, from the Shelbyville to the Marseilles, having been placed in the earlier Wisconsin, and nearly all those of the Huron-Erie lobe of the ice field having been classed as later Wisconsin.

The argument drawn from the differences in contour was supported by an overlapping upon the eastern ends of the moraines of the Lake Michigan lobe by bowldery strips that have a trend in harmony with the moraines of the Huron-Erie lobe and that contain rocks characteristic of the Huron-Erie ice. Thus the four moraines in the Bloomington morainic system of the Lake Michigan lobe, which trend west-southwest and east-northeast near their eastern ends, are crossed about at right angles by a bowldery belt which runs north-northwest and south-southeast from eastern Iroquois County, Ill., across western Benton and Warren counties, Ind., to the Wabash Valley at Attica, and which to the south of the Wabash is associated with a moraine of the Huron-Erie lobe. It was thought that the bowlder belt north of Attica, like that south of the Wabash Valley, was formed at the border of the Huron-Erie ice and that its incursion into the region occupied by moraines and till plains of the Lake Michigan lobe necessitated the earlier disappearance of the Lake Michigan lobe. In the vicinity of the bowldery strip certain deposits of till, among which is the gray till on Stone Creek near Williamsport, appear to be a product of movement from the east.

Another feature which was thought to support the division into earlier and later Wisconsin is the cross striation in western Indiana; one set of striæ bears

southward as if formed by the Lake Michigan lobe, and a later set bears westward as if formed by the Huron-Erie ice movement. It now appears, however, that the southward-pointing striæ were produced at the Illinoian rather than at the Wisconsin stage, for they occur farther east than the Lake Michigan glacier is known to have extended in the Wisconsin stage and farther south than the Wisconsin drift limit. For this reason they can not be used for differentiating the so-called earlier and later Wisconsin movements.

The early hypothesis implies great discordance in glaciation in the Lake Michigan and Huron-Erie portions of the Labrador ice field. Under it not only must the Lake Michigan ice have melted back about to the limits of the Lake Michigan basin, and have developed several very bulky moraines in the course of its recession while the Huron-Erie ice held nearly its maximum position, but the Lake Michigan ice border must afterward have maintained its position just outside the limits of the Lake Michigan basin and have formed only one prominent morainic system (the Valparaiso) while the Huron-Erie ice border was receding across Indiana and Ohio about to the limits of the Erie basin and developing several moraines in the course of its retreat. It would seem more natural for the two parts of the Labrador ice field to have had a similar mode of recession instead of this discordance, and it now seems likely that the features noted are such as might be developed where ice currents from different directions were meeting on common ground, but where neither dominated strongly over the other or persisted after the other had withdrawn or melted away.

[1]Mon. U. S. Geol. Survey, vol. 41, 1902, pp. 494-509.

The bowlder belt, though reaching 5 to 10 miles beyond the line of junction marked by the eastern termini of the ridges of the Bloomington morainic system makes really a very slight overlap in comparison with the great area of the two divisions of the Labrador ice field, and there seems no great difficulty in explaining it on the basis of slight encroachment of the eastern movement into territory which had been occupied by the Lake Michigan glacier. This overlapping may perhaps have been merely in the surface portion of the ice sheet, and thus may not have affected the basal portion. The bowlder deposition may have begun at the south at the time when the oldest of the four moraines of the Bloomington system was forming and have extended northward with the recession of the ice border along the junction of the Lake Michigan and Huron-Erie ice and not have been completed until the last of the ridges of the Bloomington system had been formed. In other words, the bowlder belt would mark a line of recession instead of the trend of an ice border.

After the development of the Bloomington morainic system there seems to have been rapid recession along the junction of the Lake Michigan and Huron-Erie lobes across the Kankakee basin and on northeastward into southern Michigan as far as the Kalamazoo Valley east of the city of Kalamazoo. Along this line are numerous bowldery patches and morainic areas that appear to pertain to an interlobate moraine, and extensive outwash aprons that make it possible to work out in a rude way the progress of the secession.

As the terms earlier and later Wisconsin were introduced under the view that there had been a great shifting and readjustment of the ice currents the present distrust of the correctness of that view necessitates the suspension of the use of the terms so long as the distrust continues. It may be necessary to revive the terms if further investigation discloses a clearly defined basis. It is probable that the outer moraine of the Green Bay lobe and, indeed, much of the Wisconsin border in Wisconsin, Minnesota, Iowa, and the Dakotas may be younger than the Shelbyville morainic system of the Illinois lobe. If such should prove to be the case, it might be convenient to refer to the older portion of the Wisconsin border as earlier Wisconsin and to the younger portion as later Wisconsin. This matter, however, is not important in the area covered by the present monograph and may be left with this passing suggestion.

Attention was directed in Monograph XLI (pp. 352-353) to certain broad, shallow valleys cut in outwash gravels of the earlier part of the Wisconsin stage in the reentrants between the East White and Miami lobes and the Miami and Scioto lobes. The morainic ridges of the main system cross the beds of these channels in such way as to show that they were later than the channeling. The cuts are shallow, being generally only 25 to 50 feet deep, but in places reach a width of 2 miles or more. The amount of work done seemed to the writer at the time Monograph XLI was written to require a considerable time, and it was referred to the interval between the earlier and later Wisconsin drift. Subsequent studies in the southern peninsula of Michigan, however, have brought to light other instances of large erosion in reentrant angles between ice lobes or in places where glacial drainage was greatly concentrated, and this erosion seems to have occurred in the ordinary recession of the ice sheet without the lapse of a long interval such as was postulated in eastern Indiana and western Ohio. The writer is not at present disposed, therefore, to allow so much time as he formerly did for the erosion of these channels, for in both of them there must have been great concentration of glacial drainage.

RETREATS AND READVANCES OF THE ICE.

The Wisconsin drift, as displayed in Illinois, Indiana, and Michigan, has several complex systems of moraines marking either halts or readvances of the ice border, between which are nearly plane-surfaced tracts over which the ice border probably retreated somewhat rapidly. In connection with the retreat of the ice sheet into and beyond the basins of the Great Lakes, large glacial lakes were developed, the drainage of which differed widely from the present system of drainage, being chiefly to the Mississippi and the Gulf of Mexico.

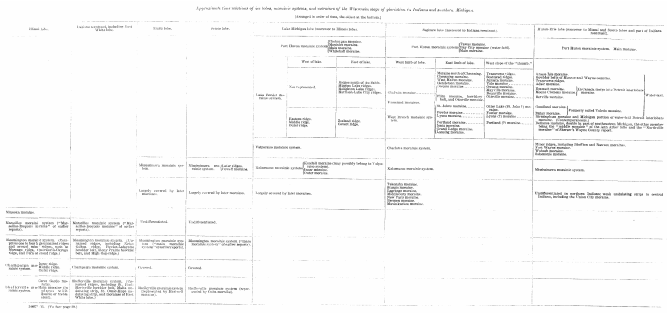
GROUPING OF THE MORAINES.

The moraines of the Wisconsin stage are more or less concentrated in groups. (See Pl. XXXII, in pocket, and table opposite this page.) Several moraines, closely crowded together, adjoin a few that are more widely spaced, and these in turn are succeeded by another closely crowded group, and then by others more widely spaced. Thus in the Illinois district the Shelbyville morainic system, formed at the culmination of the Wisconsin stage of glaciation, consists of three ridges where most deployed and of one or two where more closely crowded. North of this comes the Cerro Gordo moraine, the latest moraine of the Shelbyville system, and three weak ridges classed as the Champaign morainic system, which are distinct for most of their length, but which merge at the west into a single ridge. Thus of seven ridges three are closely combined into the great Shelbyville system, and four, whose aggregate bulk is less than that of the Shelbyville system, are spread over a space several times as great. These weaker ridges are succeeded to the north by four bulky, closely associated ridges known as the Bloomington morainic system, which in turn is succeeded in eastern Illinois by two widely spaced moraines, the Marseilles morainic system and the Minooka moraine, and in northwestern Indiana and southern Michigan by others known as the Maxinkuckee, the Bremen, the New. Paris, the Middlebury, the Lagrange, the Sturgis, and the Tekonsha, which can be compared with the Cerro Gordo moraine and the Champaign system, though they are as a whole somewhat more bulky. Next comes another series of moraines, which comprises the Kalamazoo and Valparaiso morainic systems of the Lake Michigan basin, and the Mississinawa morainic system and perhaps three or four later moraines of the Huron-Erie basin. Connecting these is a great series of moraines at the end of the Saginaw lobe, whose principal members pass through Jackson and Charlotte and which is comparable to the Bloomington and Shelbyville systems. It is followed by a series of weaker and more widely spaced moraines which extend back, in the Saginaw and Huron basins, to the Port Huron morainic system of closely aggregated ridges. This last, in turn, is followed by other wider-spaced ridges.

The moraines of the Wisconsin drift are so numerous and in places are so intricately combined that in this paper it is found advantageous to consider them in groups rather than to attempt complete correlation of each moraine across the entire region discussed. This method has nearly all the advantages of individual tracing without involving questionable correlations. It is also much simpler for the reader to follow.

The first two groups of moraines, as noted above, include those formed in the adjustment of the shrinking ice sheet to the basins that held the Lake Michigan, Saginaw, and Huron-Erie lobes. With their intermorainic tracts they include an area reaching from south of Kankakee River in western Indiana to south of Mississinawa River in eastern Indiana and extending northward into Michigan to the vicinity of Kalamazoo and Battle Creek.

The third group of moraines embraces the Kalamazoo and Valparaiso morainic systems of the Lake Michigan lobe, the Kalamazoo and Charlotte systems of the Saginaw lobe, the Mississinawa, Salamonie, Wabash, and Fort Wayne moraines of the Huron-Erie lobe, and the interlobate belts between the Lake Michigan and Saginaw lobes and between the Saginaw and Huron-Erie lobes. In this group all the bulky moraines of the southern half of the southern peninsula of Michigan are included.



[Approximate time relations of ice lobes, morainic systems, and moraines of the Wisconsin stage of glaciation in Indiana and southern Michigan]

The fourth group of moraines embraces the Lake Border morainic system of the Lake Michigan lobe, a series of weak moraines in the Saginaw basin and the moraines between the Huron and Erie basins back to the Port Huron morainic system. The moraines of this group are relatively weak except in the vicinity of the junction of the Saginaw and Lake Michigan lobes and between the Saginaw and Huron-Erie lobes.

The fifth group embraces a series of moraines which is clearly separable from earlier moraines on the western side of the Lake Michigan basin and in part of its course on the eastern side, and which appears to be correlated with the Port Huron system of moraines in the Huron basin. In Wisconsin it includes the series of red-clay moraines which are found from Milwaukee northward. On the Michigan side its correlatives embrace the Whitehall moraine, which is traceable northward from the vicinity of Muskegon, and some later moraines which appear on the borders of Lake Michigan farther north. Of these last, two ridges that lead north from near Manistee, Mich., seem to correlate with ridges on the Wisconsin side near Two Rivers; they were formed subsequent to the development of the Glenwood and Calumet beaches of Lake Chicago and the series of Arkona beaches in the Huron-Erie basin, for they override the northern ends of these beaches and thus show a readvance of the ice. On retreating from this morainic system the ice melted away from the Lake Michigan and Huron basins.

Later groups exist in the region south of Lake Superior and probably still others north of the lake in Canada, but these lie outside the region embraced in the present

discussion and they have as yet been but partly worked out.

EVIDENCE OF READVANCE OF THE ICE.

Readvance of the ice along at least a portion of the length of these bulky morainic systems is more or less evident. At its western end, from Peoria, Ill., northward, the Bloomington system overrides not only the weak moraines of the Champaign system but even extends into the ground occupied by the Shelbyville system and makes it impossible to differentiate the two. The readvance in eastern Illinois and farther east appears to have been less pronounced, the Kalamazoo and Valparaiso systems being separated from the Bloomington by fewer moraines in Illinois than in northwestern Indiana. In the Port Huron morainic system the evidence of readvance is very clear, especially on the peninsula or "thumb" of Michigan, between the southern part of Lake Huron and Saginaw Bay, where, as shown by Mr. Taylor (p. 362), the readvance caused a rise of the waters of a glacial lake outside the ice.

The supposed correlatives of the Port Huron morainic system in the Lake Michigan basin are more widely spaced than in the Huron basin; an outer member on the Wisconsin side contains a red drift carried over a drift of lighter color, as noted by Chamberlin and Alden, and later members on each side of the lake override the two higher beaches of the glacial lake Chicago, which occupied the south part of the Lake Michigan basin.

CHRONOLOGY OF THE WISCONSIN ICE SHEET.

STAGE AND SUBSTAGE.

The great morainic systems noted can scarcely be classed as recessional moraines. Instead they appear to have been formed at the culmination of a readvance of more or less consequence. These readvances are of a rank subordinate to that of glacial stages such as the Wisconsin, the Illinoian, and the Kansan and seem to require a distinct designation. They appear to be of similar rank to the readvances in the Alps that produced the Buhl, the Gschnitz, and the Daum moraines and to represent perhaps similar divisions of the glacial stage. The term "stadium," which is used in the Alps region for the part of the glacial stage falling between two marked readvances of the ice, marks an areal oscillation rather than a time interval. It seems preferable therefore to use the term "substage." Thus the Bloomington substage covers the time of deposition of the Bloomington morainic system and of all the later moraines back to the Kalamazoo-Mississinawa morainic system, including any that have been overridden by the latter system. The Kalamazoo or Mississinawa substage covers the time of deposition of the moraines of the contemporaneous Kalamazoo and Mississinawa systems and of all moraines back to or overridden by the Port Huron morainic system.

Certain features seem to indicate that the substages may eventually need subdivision, but this will not be attempted at this time. Thus certain moraines within the group embraced in a given substage show a slight forward movement into territory that had been vacated by the ice sheet; also a crowding together of subsidiary ridges in certain complex moraines is followed by wider spacing. This is notable in part of the St. Johns moraine of the Saginaw basin and is not uncommon in other moraines.

CALCULATION OF TIME.

The calculation of time involved in the disappearance of the ice sheet at the last stage of glaciation may be worked out on this basis. If the time required for the development of a morainic ridge or of a subsidiary ridge can be satisfactorily determined a rude estimate may be made of the entire time required for the retreat of the ice from the southernmost to the northernmost of the moraines that have been mapped.

The calculation must be based on areas where the moraines show the best development and on moraines winch show the fullest development of subsidiary ridges. Account must be taken not only of the visible subsidiary ridges in the moraine which displays them best but also of ridges that were possibly overridden in the course of a readvance to the culminating position. Similarly, it is insufficient to count the visible moraines of a substage; calculations must also be made for moraines that were overridden in the next succeeding substage. Calculations based on overridden material are necessarily less definite than those based on visible features, and must be given correspondingly less weight.

RETARDATION OF MOVEMENT IN THE SAGINAW LOBE.

The area covered by this monograph is probably less suitable for demonstrating the oscillatory movement of the ice border and the periodicity of the expansions and contractions of the ice than are districts in which the ice had greater freedom for wide deployment. The area was one of conflicting ice movements, the Saginaw lobe being crowded on each side by neighboring lobes. Studies in the field have brought to light evidence (see p. 128) which points to the relative stagnation of the movement or to a steady decrease in the Saginaw lobe in sharp contrast with the oscillations of the border displayed by the Lake Michigan lobe on the west and the Huron-Erie lobe on the east.

The oscillations in the Lake Michigan lobe are also somewhat peculiar, for they show a tendency to a westward shifting of the axial movement. Thus the axis of movement at the time the Shelbyville morainic system was being formed was along a line pointing toward Shelbyville, Ill., from the southern end of the Lake Michigan basin, whereas at the time the Bloomington morainic system was being developed the axial line was directed more nearly toward Peoria, Ill. Still later, the movement shifted so much farther to the west that in southern Wisconsin the moraines override those of the Bloomington system. It is probable that this shifting resulted from the great accumulations of drift on the eastern side of the Lake Michigan basin, especially in

Oceana and Mason counties, where the trend of the east shore changes from southwestward to southward. The eastern side of the Lake Michigan lobe had thus less freedom for deployment than the western, and the ice tended to hold its position on the east while it was advancing on the west.

The conflicting movements just mentioned may have served to prevent obliteration of records by burial of the glacial features such as occur in regions of oscillating ice border, and in this way the Saginaw and neighboring districts may be of exceptional value in working out the full series of moraines. As will be shown later (p. 123), the number of moraines preserved in this region is certainly greater than in the region of freer movement to the west.

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The distribution of the drumlins in reference to moraines and eskers and the preglacial topography and general configuration of the drift surface are considered; then the form and the structure are brought out. The drumlins are said to be of different ages in different parts of southern Wisconsin, some being on the pre-Wisconsin and some on the Wisconsin drift, but all are the latest product of glaciation in the region. Evidence as to the exact method of formation is meager and indecisive and no conclusions seem warranted.

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——— Postglacial outlet of the Great Lakes through Lake Nipissing and the Mattawa River: Bull. Geol. Soc. America, vol. 4, 1893, pp. 425-427.
Doubts if the Mattawa Valley is capacious enough to have served as such an outlet.

——— Proofs of the rising of the land around Hudson Bay: Am. Jour. Sci., 4th ser., vol. 1, 1896, pp. 219-228. Also in Ann. Rept. Smithsonian Inst, for 1897, pp. 359-367.
Cites evidences in support of view that a rise of 7 to 10 feet per century is in progress. See Tyrrell, J. B., for opposing evidence.

——— Evidence of northeasterly differential rising of the land along Bell River (Canada): Bull. Geol. Soc. America, vol. 8, 1897, pp. 241-250.
Character of drainage is thought to indicate that an earth movement is in progress.

——— The geological history of Lake Superior: Trans. Canadian Inst., vol. 6, 1899, pp. 45-60.
Thinks from the occurrence of Cretaceous rocks to the west that the Lake Superior basin may not have had vigorous excavation until the Tertiary period. Inclines to view that ice greatly accentuated stream erosion and that warping is likely to have aided in producing the basin of Lake Superior. Thinks preglacial outlet of Lake Ontario was through the Mohawk; that of the Erie and Huron westward from Lake Erie into the Mississippi; that of Lake Michigan southward; and that of Lake Superior perhaps via Lake Nipigon northeastward, perhaps through a river across site of Hudson Bay. Refers to Au Train outlet southward as possible. Reviews the literature to some extent.

BENEDICT, A. C, and ELROD, M. W. See Elrod and Benedict.

BENNETT, L. F., Headwaters of Salt Creek in Porter County, Ind.: Proc. Indiana Acad. Sci. for 1899, pp. 164-166.
Describes knolls and marshy tracts in a moraine at the head of the creek.

BIGSBY, J. J., Geological and mineralogical investigations in the northwest portion of Lake Huron: Am. Jour. Sci., vol. 3, 1821, pp. 254-272.
Mentions ancient beaches about Lake Huron and refers their formation to ocean water. Mentions marine fishes in the waters of the Laurentian lakes above Niagara.

——— Notes on the geography and geology of Lake Huron: Trans. Geol. Soc. London, 2d ser., vol. 1, 1824, pp. 175-210.
Discusses the transportation of the primitive rocks southward into areas of secondary rocks by the violent action of floating substances rushing from the north. Recognizes the abraded surface of the primitive rocks. Briefly discusses the effect of ice in transporting stones along the rivers and the effect of wind in heaping up the waters of the lake on the leeward coast.

——— On the erratics of Canada: Quart. Jour. Geol. Soc. London, vol. 7, 1851, pp. 215-238.
Describes loose detritus and ancient beaches on the north shore of Lake Superior and about the lower Laurentian lakes, giving altitudes of some of the beaches. Notes that both marine and fresh-water fossils occur near together in deposits on the border of the St. Lawrence Valley. Gives diagrams of levels of fresh-water and marine deposits and suggests origin of the raised beaches.

BLATCHLEY, W. S., The geology of Lake and Porter counties, Ind.: Twenty-second Ann. Rept. Dept. Geology and Nat. Res. Indiana, 1898, pp. 25-104 (mainly pp. 29-64), Pls. III-VIII.
Discusses Pleistocene geology, including beaches of Lake Chicago.

——— Geologic distribution of road materials of Indiana: Thirtieth Ann. Rept. Dept. Geology and Nat. Res. Indiana, 1905, pp. 120-132.
Discusses the distribution of glacial deposits, stream deposits of all classes, and rock formations, and gives special attention to the distribution of gravel and bowlders.

——— Road materials of a portion of central southern Indiana: Thirtieth Ann. Rept. Dept. Geology and Nat. Res. Indiana, 1905, pp. 878-880, 889-890, 896-898, 934-936.
Finds only a small area of glacial material in the counties discussed; treats this and the stream deposits and also conglomerates of preglacial age.

——— Gold and diamonds in Indiana: Twenty-seventh Ann. Rept. Dept. Geology and Nat. Res. Indiana, 1903, pp. 11-47.
Discusses the relation to the glacial formations.

——— and ASHLEY, G. H., Lakes of northern Indiana and their associated marl deposits: Twenty-fifth Ann. Rept. Dept. Geology and Nat. Res. Indiana, 1900, pp. 31-321.
Describes the sounding of many lakes and gives maps. Discusses the origin of marl.

BORDEN, W. W., Reports upon counties of southern Indiana. Clark and Floyd counties: Fifth Ann. Rept. Geol. Survey Indiana, 1873, pp. 178-179. Scott and Jefferson counties, Sixth Rept., 1873, pp. 115-118. Jennings and Ripley counties, Seventh Rept., 1875, pp. 171-174, 178, 195-196.
Notes the occurrence of small quantities of gold and much buried timber in the glacial deposits and buried soils under the drift.

BOWMAN, AMOS, Testimony of Ottawa clays and gravels to the expansion of the Gulf of St. Lawrence and Canadian lakes within the human period: Ottawa Naturalist, vol. 1, 1888, pp. 149-161.
Gives results of personal observations and summarizes work of other observers.

BOWMAN, ISAIAH, A typical case of stream capture in Michigan: Jour. Geology, vol. 12, 1904, pp. 326-334.
Discusses the capture of a very small tributary of Huron River near Ypsilanti by the widening of the Huron Valley until it cut into the path of the tributary.

——— Flowing wells and municipal water supplies of Clinton, Eaton, Barry, Ionia, Montcalm, Ottawa, and northern Allegan counties, Mich.: Water-Supply Paper U. S. Geol. Survey No. 182, 1906, pp. 155-169, 225-226.

BOWNOCKEE, J. A., A deep preglacial channel in western Ohio and eastern Indiana: Am. Geologist, vol. 23, 1899, pp. 178-182, with map.
Traces a deep channel by borings from Shelby County, Ohio, to Blackford County, Ind.

BRADLEY, F. H., Geology of Vermilion County, Ind.: First Ann. Rept. Geol. Survey Indiana, 1869, pp. 138-141.
Notes buried soil and distinct sheets of glacial drift.

——— Grundy, Will, Kankakee, Iroquois, Vermilion, Edgar, Ford, and Champaign counties, Ill.: Illinois Geol. Survey, vol. 4, 1870, pp. 190-194, 205-209, 222-230, 236-238, 241-244, 266, 272-274.
Notes buried soil and distinct drift sheets in several counties.

BREEZE, F. J., The valley of the lower Tippecanoe River: Proc. Indiana Acad. Sci., 1901, pp. 215-216.
Presents map and discusses width of valley and of stream.

BRETZ, J. H., Glacial features of Genesee County [Mich.]: The Schoolmaster (an educational journal published monthly at Saginaw, Mich.), Feb. and Mar., 1907, pp. 482-487 and 530-539.
Gives a general description of the glacial and lake formations of Genesee County and a map covering most of the county. Discusses the topography and gives a clear account of the recession of the ice sheet and the development of moraines, till plains, eskers, glacial drainage channels, etc., the succeeding lake stages with beaches, deltas, etc., and the relation of all of these features to the present drainage.

BROWN, R. T., General sketch of geology of Indiana: Third Rept. Board Agri., 1853, pp. 299-322.

——— Reports upon counties in Indiana: Fountain County drift and buried channels: Eleventh Ann. Rept. Dept. Geology and Nat. Hist. Indiana, 1881, pp. 91-94; Marion County, glacial deposits, terraces, buried channels, postglacial drainage, well sections, etc.: Twelfth Rept., 1882, pp. 81-96; Morgan County, glacial deposits (including gold and diamonds), drainage features, etc.: Thirteenth Rept., 1883, pp. 79-83; Hamilton and Madison counties, glacial deposits and postglacial drainage: Fourteenth Rept., 1884, pp. 22-26, 32-37; Hancock County, glacial features, drainage, and soils: Fifteenth Rept., 1886, pp. 187-197.
States that buried soils occur between drift sheets in several of these counties.

BURT, W. A., In S. Ex. Doc. No. 1, 31st Cong., 1st sess., 1849, pt. 3, p. 820.
Notes that Lake Superior was formerly much larger than now.

CABLE, E. J., Road materials of a portion of central Indiana: Thirtieth Ann. Rept. Dept. Geology and Nat. Res. Indiana, 1905, pp. 656-674, 681-755.
The occurrence of gravel deposits in workable quantity in several counties discussed is described in some detail.

CAMPBELL, J. L., Report upon the improvement of the Kankakee River and the drainage of the marsh lands in Indiana, 34 pp. with map of Kankakee region, Indianapolis, 1883.
Presents a line of levels along the axis of the Kankakee basin.

CAMPBELL, J. T., Topographical phenomena in Indiana: Am. Naturalist, vol. 18, 1884, pp. 367-379.
Explains low inclination of south-facing drift slopes by a creeping of the deposits, favored by the deposition of drift by a southward-moving current of ice. Distrusts interpretation referring the low inclination to alternations of freezing and thawing on that slope.

——— Source of supply to lateral and medial moraines: Abstract in Proc. Am. Assoc. Adv. Sci., vol. 40, 1891, pp. 255-256.
Lower layers of ice are thought to bring up material to higher levels at abrupt bends as streams do.

——— Evidence of a local subsidence in the Interior: Jour. Geology, vol. 9, 1901, pp. 437-438.
Recent levelings of a locality in Indiana where bench marks were established in 1883 show a southward differential depression which it is thought may have been produced by the Charleston earthquake.

CARNEY, FRANK, The metamorphism of glacial deposits: Jour. Geology, vol. 17, 1909, pp. 473-487.
Discusses induration or cementation, leaching, etc., in Illinoian drift compared with Wisconsin.

——— Raised beaches of the Berea, Cleveland, and Euclid sheets, Ohio: Bull. Sci. Lab. Denison Univ., vol. 14, 1909, pp. 262-287. Abandoned shore lines of the Oberlin quadrangle, Ohio: Bull. Sci. Lab. Denison Univ., vol. 15, 1910, pp. 101-117.
These two papers present results of detailed field study of beaches in several quadrangles on the south shore of Lake Erie.

——— Some proglacial lake shorelines of the Bellevue quadrangle, Ohio: Bull. Sci. Lab. Denison Univ.. vol. 17, March, 1913, pp. 231-246, 4 figs.

CARR, M. E., and MCLANDON, W. E., Soil survey of the Saginaw area, Michigan: Field operations Bur. Soils in 1904, U. S. Dept. Agri., 1905, 40 pp. and map.
Discusses soils, agricultural methods, and conditions in an area of 984 square miles around Saginaw.

CHALMERS, ROBERT, Artesian borings, surface deposits, and ancient beaches in Ontario: Summary Rept. Geol. Survey Canada for 1902, pp. 268-279.
Notes occurrence of two bowlder clays and presents discussion (with map) of several shore lines in southwestern Ontario. Differential uplift is recognized, but the amount of uplift is not determined.

CHAMBERLIN, T. C., On the extent and significance of the Wisconsin Kettle moraine: Trans. Wisconsin Acad. Sci., vol. 4, 1878, pp. 201-234.
Describes the morainic features and their relation to striæ in eastern Wisconsin, and the topographic relations and position of the moraine from Wisconsin eastward to the Atlantic coast. The development of ice lobes in each of the great basins is discussed and mapped.

——— Le Kettle moraine et les mouvements glaciaires que lui ont donné naissance: Compt. rend. Cong. géol. inter nal, sess. 1878, Paris, 1880, pp. 254-268.
Brings out the influence of basins in developing lobes of ice as determined by the distribution of the Kettle moraine and the striæ bearing toward it.

——— The bearing of some recent determinations on the correlation of the eastern and western terminal moraines: Am. Jour. Sci., 3d ser., vol. 24, 1882, pp. 93-97.
States that the moraines which stand at the drift border in the eastern part of the United States lie far inside (north of) the drift border in the interior.

——— Origin of the Great Lakes basins and the Great Lakes epoch: Geology of Wisconsin, vol. 1, 1883, pp. 288-295.
Discusses the ancient lake deposits, the changes of level, the reversal of drainage, and the work of the present lakes. In vol. 2, 1877, pp. 231-232, gives statement showing the rate of erosion of the lake shore in Racine County, Wis., which throws light on the length of time Lake Michigan has been at work.

——— Preliminary paper on the terminal moraine of the second glacial epoch: Third Ann. Rept. U. S. Geol. Survey, 1883, pp. 291-402.
Defines the several classes of drift and types of drift topography. Gives a comprehensive treatment of glacial lobation and describes a prominent morainic system whose course is outlined from the Atlantic seaboard to the Missouri Coteau.

——— The rock scorings of the great ice invasions: Seventh Ann. Rept. U. S. Geol. Survey, 1888, pp. 174-248.
Discusses and illustrates various phases of glacial scoring in the United States and British Columbia.

——— Bowlder belts distinguished from bowlder trains: Bull. Geol. Soc. America, vol. 1, 1890, pp. 27-31.
Says that bowlder belts conform to distribution of moraines, and bowlder trains to the bearing of striæ.

——— The attitude of the eastern and central portions of the United States during the glacial period: Am. Geologist, vol. 8, 1891, pp. 267-275.
In the earlier stages of glaciation the outwash from the ice was weaker and the attitude of the land probably flatter than in the later stages, though in the eastern portion the altitude was low at the close of glaciation.

——— Nature of the englacial drift of the Mississippi basin: Jour. Geology, vol. 1, 1893, pp. 47-60.
Treats of the amount and character of englacial drift, and outlines the course of bowlder belts in Indiana and Ohio which are thought to represent englacial transportation.

——— Glacial phenomena of North America: Geikie's Great ice age, 3d ed., 1895, pp. 724-775.
A comprehensive statement of North American glaciology. Names for the Kansan, Iowan, and Wisconsin drift sheets are introduced.

——— Classification of American glacial deposits: Jour. Geology, vol. 3, 1895, pp. 270-277; vol. 4. 1896, pp. 872-876.
Extends nomenclature given in Geikie's Great ice age so as to include the Illinoian drift sheet and the several interglacial soils or weathered zones.

——— An attempt to frame a working hypothesis of the cause of glacial periods on an atmospheric basis: Jour. Geology, vol. 7, 1899, pp. 545-584, 667-685, 751-787.
The function of carbon dioxide, the agencies of depletion and enrichment, and the varying rates of action are considered and applied to known glacial periods and to the oscillations from glacial to interglacial epochs; discusses also the agencies of localization of glaciation.

——— A contribution to the theory of glacial motion: Decen. Pub. Univ. Chicago, vol. 9, 1904, pp. 193-206.
Asserts that the differences between glacial ice and ice formed by freezing water are such that experiments on one throw little light on the other. The behavior of glacial ice under gravitative stress is discussed at some length.

——— and SALISBURY, R. D., The Pleistocene or glacial period: Geology, vol. 3, 1906, pp. 327-516, especially pp. 394-405.

CHAPMAN, E. J., Notes on the drift deposits of western Canada and on the ancient extension of the lake area of that region: Canadian Jour., new ser., vol. 6, 1861, pp. 221-229; vol. 8, 1863, pp. 457-462.
Notes occurrence of existing species of fresh-water mollusks in stratified drift and old lake ridges. Disputes Lyell's interpretation that high beaches around Lake Ontario were formed about an arm of the ocean and suggests that they were produced by a fresh-water lake.

CLAPP, F. G., and FULLER, M. L., The marl loess of the lower Wabash Valley: Bull. Geol. Soc. America, vol. 14, 1903, pp. 153-176.
Attempts to discriminate between water-laid and wind-deposited loess.

CLAYPOLE, E. W., On the preglacial geography of the region of the Great Lakes: Canadian Naturalist, vol. 8, 1878, pp. 187-206; vol. 9, 1881, pp. 213-227.
Bases discussion on data from borings.

——— Preglacial origin of the basins of Lakes Erie and Ontario: Proc. Am. Assoc. Adv. Sci., vol. 30, 1882, pp. 147-159.
Opposes hypothesis of glacial excavation of the lake basins on the ground that the amount of drift was inadequate to refill them. Cites observations in support of view that the basins are in the line of old river valleys.

CLAYPOLE, E. W., Buffalo and Chicago, or "What might have been": Am. Naturalist, vol. 20, 1886, pp. 856-862.
A slight change only is needed, to divert the drainage of Lakes Superior, Michigan, Huron, and Erie from Niagara to the Chicago outlet.

CLINTON, DEWITT, On certain phenomena of the Great Lakes of North America: Trans. New York Lit. and Phil. Soc, vol. 2, 1817, pt. 1, pp. 1-33.
Discusses annual and short-period fluctuations of lake level.

COLE, L. J., The delta of the St. Clair River: Geol. Survey Michigan, vol. 9, 1903, pt. 1, pp. 1-28.
Discusses the character and extent of the delta and its present rate of growth. Evidence is found that the Lake St. Clair bed has been a land surface during part of the postglacial time, presumably while the Nipissing Great Lakes were discharging eastward past North Bay, Ontario.

COLLETT, JOHN, Reports of Indiana Geological Survey contain brief discussions of glacial deposits, as follows: Sullivan County, Second Ann. Rept. Geol. Survey Indiana, 1870, pp. 225-228; Dubois, Pike, Jasper, White, Carroll, Cass, Miami, Wabash, and Howard counties, Third and Fourth Repts., 1871 and 1872, pp. 193-195, 240-241, 291-293; Warren and Knox counties, Fifth Rept., 1873, pp. 191-195, 315-320; Brown County, Sixth Rept., 1874, pp. 77-84; Owen and Montgomery and part of Clay County, Seventh Rept., 1875, pp. 301-308, 361-371, 393, 401-409, 423-426; Shelby County, Eleventh Ann. Rept. Dept.

Geology and Nat. Hist., 1881, pp. 56-69; Posey County, Thirteenth Rept., 1883, pp. 45-48.

COMSTOCK, F. M., Ancient lake beaches on the islands of Georgian Bay: Am. Geologist, vol. 33, 1904, pp. 310-318.
Describes beaches on three islands in the southeast arm of Georgian Bay.

COOPER, W. F., Water supply of the lower peninsula of Michigan: Rept. State Board Geol. Survey for 1903, pp. 47-95.
Briefly discusses artesian areas, springs, wells, topography, and water power in Lenawee, Hillsdale, Branch, St. Joseph, and Cass counties, and records of wells in other parts of the peninsula,

——— Geology of Bay County, Mich.: Rept. State Board Geol. Survey for 1905, pp. 137-426.
Presents records of coal borings in which glacial deposits are conspicuous.

——— Water supplies of Bay County, Mich.: Water-Supply Paper U. S. Geol. Survey No. 183, 1906, pp. 115-120.
Chiefly a discussion of underground waters and especially of flowing wells.

——— Geology and physical geography of Michigan: Ninth Rept. Mich. Acad. Sci., 1907, pp. 136-144.
Gives planimeter measurements of areas between each 100-foot contour based on Pl. II, Water-Supply Paper U. S. Geol. Survey No. 182, 1906.

COULTER, J. M., Some glacial action in Indiana: Science, vol. 2, 1883, p. 6; vol. 3, 1884, pp. 748-749.
Gives bearing of glacial striæ near Darlington.

COWLES, H. C., The physiographic ecology of northern Michigan: Science, vol. 12, 1900, pp. 708-709; Bot. Gazette, vol. 31, 1901, pp. 73-182.
The physiographic ecology of a large area at the head of Lake Michigan is discussed with fullness in the Botanical Gazette article.

COX, E. T., Jackson County, Ind.: Sixth Rept. Geol. Survey Indiana, 1874, pp. 41-42, 55-60.
Recognizes “Chestnut Ridge” to be morainic and gives well sections along it.

——— Glacial drift: Combined Eighth, Ninth, and Tenth Ann. Repts. Geol. Survey Indiana, 1876, 1877, and 1878, pp. 98-120.
Discusses glaciation generally and gives an outline of the extent of drift and the direction of the ice movement.

DAVIS, C. A., Bot. Gazette for June, 1898, pp. 453-455.
Discusses the geologic history of the tract at the head of Saginaw Bay and the several resulting types of soil.

——— A contribution to the natural history of marl: Jour. Geology, vol. 8, 1900, pp. 485-503; vol. 9, 1901, pp. 491-506. Also Geol. Survey Michigan, vol. 8, pt. 3, 1903, pp. 65-102.
Refers the accumulation of marl largely to the genus Chara.

——— Flowing wells of part of Oakland County, Mich.: Water-Supply Paper U. S. Geol. Survey No. 182, 1906, pp. 184-188. Flowing wells and municipal water supplies of the southern part of the Saginaw Bay drainage basin in Michigan: Water-Supply Paper U. S. Geol. Survey No. 183, 1907, pp. 121-245.
These water-supply reports discuss morainic and other glacial features, including the deposits of the glacial lakes, and give numerous well records showing the structure of the glacial deposits.

——— Peat deposits of the Ann Arbor quadrangle: Ann Arbor folio (No. 155), Geol. Atlas U. S., U. S. Geol. Survey, 1908.
Briefly discusses the occurrence and uses of peat.

——— Peat, essays on its origin, uses, and distribution in Michigan: Rept. State Board Geol. Survey Michigan for 1906, pp. 93-395.
Discusses the ecology of peat formation, the formation, character, and distribution of peat bogs in the northern peninsula, and the economics of peat in considerable detail.

——— Geology of the Walnut Lake region: Ann. Rept. State Board Geol. Survey Michigan for 1907, pp. 164-173.
Briefly discusses the glacial geology of part of Oakland County, Mich.

——— Glacial phenomena in the Marquette region: Ninth Rept. Michigan Acad. Sci., 1907, pp. 132-135.
Discusses the probable influence of the Huron Mountains on glacial movements.

——— Peat deposits as geological records: Tenth Rept. Michigan Acad. Sci., 1908, pp. 107-112.
Considers the varying rate of peat growth in the light of geologic conditions and directs attention to submerged peat beds on the Atlantic coast.

DAVIS, C. A., Geology of Tuscola County, Mich.: Rept. State Board Geol. Survey Michigan for 1908, pp. 121-346, 1909.
Discusses in considerable detail the physical geography, glacial features, soils, bedrock geology, native vegetation, and underground-water supplies. A topographic map based on railroad and drainage-ditch levels and aneroid observations brings out clearly the leading glacial and physiographic features.

DAVIS, W. M., The ancient outlet of Lake Michigan: Pop. Sci. Monthly, vol. 46, 1895, pp. 217-229.
Reviews previous descriptions and presents results of field study and topographic maps along the outlet.

DAWSON, J. W., Acadian geology, London, 3d ed., 1878, pp. xxvi, 697, suppl. 102 pp.
Refers the excavation of the Great Lakes to a time of continental submergence when polar currents flowing southward cut deeply into the strata. Considers the so-called lake ridges, moraines, and osars to be the record of old sea margins (pp. 70-71, suppl. pp. 18-24).

——— Canadian ice age, Montreal, 1893, 301 pp.
A compilation of numerous papers dealing almost entirely with Pleistocene deposits in Canada. The discussion of Pleistocene fossils is especially valuable.

DESOR, ÉDOUARD, Superficial deposits of the Lake Superior land district: Foster and Whitney Rept., Ex. Doc. No. 4, 31st Cong., 1st sess., 1851, pp. 232-270. Also Am. Jour. Sci., 2d ser., vol. 13, 1851, pp. 93-109.
Discusses the several classes of drift, the terraces, and the high beaches, and concludes that glaciation was followed by deep submergence. Also discusses modern shore phenomena and stream work.

——— Dunes on the shores of the upper American lakes: Proc. Boston Soc. Nat. Hist., vol. 3, 1853, p. 207; vol. 4, 1854, pp. 41-42.
Remarks that though no tidal action is present sand flats are exposed to wind action.

DOUGLAS, C. C., Report on Ingham and parts of Eaton and Jackson counties, Mich.: Second Ann. Rept. State Geologist, H. Doc. No. 13 (No. 4), 1839, pp. 66-77.
Briefly discusses drift and describes the two gravel ridges known as the Mason and the Williamstown-Dansville eskers.

——— General remarks on marl and other deposits and features of Jackson, Calhoun, Kalamazoo, Eaton, Ionia, and Kent counties: Third Ann. Rept., State Geologist, H. Doc. No. 8, 1840, pp. 54-62.

——— Remarks on the general character of the northern portion of the lower peninsula: Fourth Ann. Rept. State Geologist, H. Doc. No. 27, 1841, pp. 98-111.
Discusses topography and great thickness of drift. Notes a shore line (Algonquin beach) on Mackinac Island and bordering mainlands and estimates it to be 140 feet above the lake.

DRYER, C. R., Reports on counties in Indiana as follows: Dekalb and Allen counties: Sixteenth Ann. Rept. Dept. Geology and Nat. Hist. Indiana, 1889, pp. 98-130; Steuben and Whitley counties: Seventeenth Rept., 1892 pp. 114-134, 160-170; Noble and Lagrange counties: Eighteenth Rept., 1894, pp. 17-32, 72-82; Drift of the Wabash-Erie region: Eighteenth Rept., 1894, pp. 83-90.
In large part describe the glacial deposits. The Allen County report names Lake Maumee and describes its beach.

——— Studies in Indiana geography, Inland Pub. Co., Terre Haute, 1897, 110 pages.
Treats geographic features, glacial deposits (by Leverett), the Erie-Wabash region and morainic lakes of Indiana; discusses natural resources and changes produced by civilization; short history of the Great Lakes (by Taylor).

——— Eskers and esker lakes of northeastern Indiana: Jour. Geology, vol. 9, 1901, pp. 123-129.
Suggests “esker lake” as name for bodies of water occupying depressions closely connected with esker ridges.

EDMUNDS, E. S., Geology of Lagrange County, Ind.: Kansas City Review, vol. 2, 1879, pp. 500-508; vol. 3, 1880, pp. 28-33.
Very discursive; bears a little on Lagrange County.

ELLIS, R. W., Road materials of southeastern Indiana: Thirtieth Ann. Rept. Indiana Dept. Geology and Nat. Res., 1905, pp. 766-871.
Pertains only in part to glacial deposits, and those chiefly the glacial gravels of the Ohio Valley and of the East-White River valley.

ELROD, M. N., Reports on Quaternary features and deposits of counties in Indiana as follows: Bartholomew County: Eleventh Ann. Rept. Dept. Geology and Nat. Hist. Indiana, 1881, pp. 150-172; Decatur County: Twelfth Rept., 1882, pp. 139-145; Rush County: Thirteenth Rept., 1883, pp. 100-107; Fayette and Union counties: Fourteenth Rept., 1884, pp. 41-47, 55-58, 61-64, 70-71.
Notes a buried soil between drift sheets in much of the region covered. Approximately outlines the extent of the later or Wisconsin drift.

——— and BENEDICT, A. C., Geology of Wabash County, Ind.: Seventeenth Ann. Rept. Geology and Nat. Res. Indiana, 1891, pp. 238-255; Geology of Cass County: Nineteenth Rept., 1894, pp. 17-39.
Presents drift sections and well records and briefly discusses drift deposits.

FAIRCHILD, H. L., Glacial waters in the Lake Erie basin: Bull. New York State Mus. No. 106, 1907, 86 pp.
Discusses the glacial recession from the highlands south of Lake Erie to the basin of Lake Ontario, with special reference to the ice-border drainage. Gives very little information concerning the moraines but interprets the lake history somewhat elaborately.

FAIRCHILD, H. L., Drumlins of central western New York: Bull. New York State Mus. No. 111, 1907, 52 pp. and 47 pls.
Gives a full description and interpretation, accompanied by contour maps and numerous photographic illustrations, of one of the principal drumlin areas of North America. Evidence in support of the constructional development by slow accretion is clearly presented.

——— Pleistocene geology of New York State: Bull. Geol. Soc. America, vol. 24, No. 1, Mar. 25, 1913, pp. 133-162; Science, new ser., vol. 37, Feb. 14 and 21, 1913, pp. 237-249, 290-299.

FALL, DELOS, Marl and clay analyses: Geol. Survey Michigan, vol. 8, pt. 3, 1903, pp. 352-353.
Gives 37 analyses, chiefly by Fall.

FARNSWORTH, P. J., The Great Lake basins: Science, vol. 20, 1892, p. 74.
Presents the outgrown view that the lakes are pools left by the old “Azoic” sea.

FEATHERSTONAUGH, G. W., On the ancient drainage of North America and the origin of the cataract of Niagara: Am. Jour. Geology and Nat. Sci, vol. 1, 1831, pp. 13-21.
Not examined.

FIPPEN, E. O., and RICE, T. D., Soil survey of Allegan County, Mich., Bur. Soils U. S. Dept. Agr., 1901, pp. 93-134, with map.
Brings out imperfectly the relation of the soils to the ice sheet by a classification based upon mechanical analyses.

FINCH, JOHN, Age of basins of Lake Erie and St. Lawrence River: Am. Jour. Sci., vol. 27, 1835, p. 151.

FOSTER, J. W., Presidential address before American Association for the Advancement of Science: Proc. Am. Assoc. Adv. Sci., vol. 19, 1871, pp. 1-19.
Notes the occurrence of marine crustaceans in Lake Michigan and argues that they indicate a former connection between the Great Lakes and the ocean.

FOSTER, J. W., and WHITNEY, J. D., Ex. Doc. No. 4, 31st Cong., special sess. Sen., 1851, pp. 176-177, 183-189.
Briefly discusses the origin of the basins of Lakes Michigan and Huron and the evidences of denudation and subsidence.

FULLER, M. L., Pleistocene geology: Ditney folio (No. 84), Geol. Atlas U. S., U. S. Geol. Survey, 1902.
Recognizes and discusses glacial, water-laid, and wind deposits of southwestern Indiana.

——— Failure of wells along the lower Huron River, Mich., in 1904: Rept. State Geologist for 1904, pp. 1-29, Pl. I. Also Water-Supply Paper U. S. Geol. Survey No. 129, 1906, pp. 129-147.
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——— Waters of the upper peninsula of Michigan: Rept. State Board Geol. Survey Michigan for 1903, pp. 113-167.

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——— Water resources of Indiana and Ohio: Eighteenth Ann. Rept. U. S. Geol. Survey, pt. 4, 1897, pp. 419-559.
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——— Review of the glacial geology of the southern peninsula of Michigan: Sixth Rept. Mich. Acad. Sci., 1905, pp. 100-110.
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——— Drumlins in the Grand Traverse (Mich.) region (abstract): Bull. Geol. Soc. America, vol. 16, 1906, p. 577.
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These two papers present reports by Bowman, Cooper, Davis (C. A.), Fuller (M. L.), Gregory (W. M.), Lane, McLouth, Nellist, Sherzer, and Udden (Jon A.), as well as by Leverett. Describes about 300 flowing-well areas, all public supplies in cities and villages having waterworks, and the general underground-water conditions of the peninsula.

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——— Western Indiana bowlder belts: Proc. Indiana Acad. Sci., 1900, pp. 192-194.
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——— Wabash River terraces in Tippecanoe County, Ind.: Proc. Indiana Acad. Sci., 1901, pp. 237-243.
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——— History of Wea Creek in Tippecanoe County, Ind.: Proc. Indiana Acad. Sci., 1901, pp. 244-247.
The history is interpreted on the hypothesis of the existence of transient lakes between moraines due to an assumed blocking of the Wabash Valley to the west by the ice sheet.

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Outlines the course of morainic ridges and other glacial features in Jay County, and discusses the structure and constitution of the drift. Notes the great number of bowlders in parts of Johnson County, but considers them the residue from the erosion of a thick till sheet instead of a deposit at the ice margin.

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——— Water supplies of Muskegon County: Water-Supply Paper U. S. Geol. Survey No. 183, pp. 25-45.
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MUDGE, E. H., Observations along the valley of Grand River, Michigan: Am. Geologist, vol. 12, 1893, pp. 284-288.
Describes glacial features of the region.

——— Drainage systems of the Carboniferous area of Michigan: Am. Geologist, vol. 14, 1894, pp. 301-308.
Describes the topography and discusses the origin of the river systems.

——— Central Michigan and the postglacial submergence: Am. Jour. Sci., 3d ser., vol. 50, 1895, pp. 442-445.
Brings evidence from a bar in the Grand River valley that a west-flowing stream of considerable strength and volume discharged from the Saginaw basin through this valley—evidence which opposes the view that the valley was occupied by a strait at sea level.

——— Some features of preglacial drainage in Michigan: Am. Jour. Sci., 4th ser., vol. 4, 1897, pp. 383-386.
Estimates southern peninsula of Michigan to have greatest average thickness of drift found in area of its size in North America, yet the old topography is not completely buried. Conjectures, by means of borings in the great depressions of the State, the general course of a few preglacial valleys. Accepts Spencer's interpretation that the main stream flowed from the Lake Michigan toward the Saginaw Bay basin; but gives a map showing that the valleys converge toward Lake Michigan.

——— Mouth of Grand River, Michigan: Am. Jour. Sci., 4th ser., vol. 8, 1899, pp. 31-34.
Describes deposits where Grand River enters the glacial lake outlet in eastern Ionia County that throw light upon the height of water in the outlet.

MUDGE, E. H., Further notes upon preglacial drainage in Michigan: Am. Jour. Sci., 4th ser., vol. 10, 1900, pp. 158-160.
Discusses the bearing of certain well records on old drainage.

NELLIST, J. F., Water supplies of Kent County, Mich.: Water-Supply Paper U. S. Geol. Survey No. 182, 1906, pp. 267-278.
Discusses flowing-well areas and municipal supplies.

NEWBERRY, J. S., The surface geology of the basins of the Great Lakes, etc.: Am. Naturalist, vol. 4, 1871, pp. 193-218. Also Annals New York Lyceum Nat. Hist., vol. 9, 1871, pp. 213-534. A briefer paper appears in Proc. Boston Soc. Nat. Hist., vol. 9, 1865, pp. 42-46.
Asserts that the lake basins have a connected drainage system lower than the present and suggests that this was followed by the ice sheet even to a movement from Lake Erie into Lake Ontario. Thinks that the ice produced the broad and deep boat-shaped basins, and that a large inland sea followed the glacial epoch and distributed bowlders and gravel and produced lake ridges.

——— On the structure and origin of the Great Lakes: Proc. New York Lyceum Nat. Hist., 2d ser., 1874, pp. 136-138.
Gives ice erosion as well as preglacial drainage a prominent role. A similar discussion appears in Proc. Am. Philos. Soc, vol. 20, 1883, pp. 91-95.

——— Surface geology: Geology of Ohio, vol. 2, 1874, pp. 1-80, 183-186, 197-204, 206-210.
Gives much attention to the origin and history of the Great Lakes. Earlier reports in Rept. Progress Ohio Geol. Survey for 1869, and in vol. 1, 1873, discuss the history of the Great Lakes to some extent.

——— Drift deposits of Indiana: Fourteenth Ann. Rept. Dept. Geology and Nat. Hist. Indiana, 1884, pp. 85-97.
Gives general resume of the origin and structure of the drift deposits without special application to Indiana.

NEWSOM, J. F., Drainage of southern Indiana: Jour. Geol., vol. 10, 1902, pp. 166-181.
Compares postglacial and preglacial drainage and discusses effect of glaciation on drainage and on topography.

OWEN, RICHARD, Geological reconnaissance of Indiana, 1859-60, 368 pp., Indianapolis, 1862.
Briefly discusses glacial deposits in connection with notes pertaining to each of many counties in central and northern Indiana. Calls attention to Gilboa Ridge in Benton County, to bowlder belts in Benton and Warren counties, to gold in the drift of Carroll, Clinton, Henry, and Brown counties, and to numerous other Pleistocene features.

PETER, ROBERT, A report of the chemical analyses of 33 soils of Indiana: Owen's Geological reconnaissance of Indiana, 1859-60, pp. 241-268.

PHINNEY, A. J., Reports upon drift and surface geology of the following counties of Indiana: Delaware County: Eleventh Ann. Rept. Dept. Geology and Nat. Hist. Indiana, 1881, pp. 126-136; Randolph County: Twelfth Rept,, 1882, pp..177-184; Grant County: Thirteenth Rept,, 1883, pp. 138-143: Henry County and parts of Randolph, Delaware, and Wayne counties: Fifteenth Rept., 1886, pp. 97-116.

——— The natural-gas field of Indiana: Eleventh Ann., Rept. U. S. Geol. Survey, 1891, pt. 1, pp. 589-742.
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PIERCE, JAMES, Notice of the peninsula of Michigan in relation to its topography, scenery, agriculture, population, resources, etc.: Am. Jour. Sci., vol. 10, 1826, pp. 304-319.
Gives a good description for that early date.

PLUMMER, J. T., Geology about Richmond, Ind.: Am. Jour. Sci., vol. 44, 1843, pp. 281-313.
Notes the striæ, buried wood, bowlders, soils, springs, etc., in vicinity of Richmond, Ind.

PRICE, J. A., Road materials in Allen County, Ind.: Thirtieth Ann. Rept. Dept. Geology and Nat. Res. Indiana, 1905, pp. 275-314.
Discusses briefly the topography, drainage, both glacial and postglacial, and general glacial history of Allen County and the sand and gravel deposits in their generic relations. Describes in detail the workable deposits of gravel.

RAMSEY, A. C., On the glacial origin of certain lakes, etc.: Quart. Jour. Geol. Soc. London, vol. 18, 1862, pp. 185-204. Also Am. Jour. Sci., 2d ser., vol. 35, 1863, pp. 324-345.
Notes the abundance of lakes in glaciated regions, and shows that some of them are in rock basins apparently excavated by ice.

RICE, T. D., and FIPPEN, E. O. See Fippen and Rice.

——— and GEIB, W. J. See Geib and Rice.

RIES, HEINRICH, Clays and shales of Michigan: Michigan Geol. Survey, vol. 8, pt. 1, 1900, pp. 1-67.
Includes tests and uses of surface clays and glacial clays as well as of shales.

ROMINGER, CARL, Geology of the Lower Peninsula of Michigan: Michigan Geol. Survey, vol. 3, 1873-1876, pp. 1-22.
Thinks that glacial deposits were acted on by floods and floating ice late in the glacial epoch.

ROY, THOMAS, On the ancient state of the North American continent: Proc. Geol. Soc. London, vol. 2, 1837, pp. 537-538.
Refers all the terraces and gravelly ridges from the level of Lake Ontario up to 1,000 feet above sea to the action of a great lake.

RUSSELL, I. C., Sand bars in Lake Michigan and arms of the Great Lakes and of their hydrographic basins: Geologic history of Lake Lahontan: Mon. U. S. Geol. Survey, vol. 11, 1885, pp. 92-93.

——— Geologic history of the Laurentian basin: Jour. Geology, vol. 1, 1893, pp. 394-408.
A discussion of the problems connected with the Great Lakes.

——— Geography of the Laurentian basin: Bull. Am. Geog. Soc, vol. 30, 1898, pp. 226-254.
Presents a review of the glacial history of the Great Lakes region.

RUSSELL, I. C., Lakes of North America, Ginn & Co., Boston, 1897, pp. 96-104.
Contains a discriminating review of part of the literature of the Pleistocene Great Lakes.

——— The Portland cement industry in Michigan: Twenty-second Ann. Rept. U. S. Geol. Survey, 1900-1901, pt. 3, pp. 646-664.
Discusses the mode of occurrence, physical properties, chemical composition, and origin of marl deposits.

——— A geological reconnaissance along the north shores of Lakes Huron and Michigan: Rept. State Board Geol. Survey Michigan, 1904, pp. 33-113. A geologic reconnaissance in Menominee, Dickinson, and Iron counties, Mich.: Rept. State Board Geol. Survey Michigan for 1906, pp. 1-91.
These reports describe the glacial deposits, lake beaches, soils, and pre-Pleistocene geology, and give considerable attention to drumlins, which are said to have been chiefly formed by the sculpturing of a drift sheet that was overridden by the ice. Illustrated by several good photographs.

——— Drumlin areas in northern Michigan (abstract): Seventh Rept. Michigan Acad. Sci., 1905, pp. 36-37. Also Bull. Geol. Soc. America, vol. 16, 1906, pp. 577-578.
Discusses two drumlin areas, Le Cheneaux and Menominee, and infers that they are largely forms sculptured by a fresh ice advance over an earlier drift sheet.

——— Report on the water supply of the Ann Arbor Water Co.: Proc. Ann Arbor Council, Nov. 13, 1905, 22 pp.
Discusses the geological conditions at the wells of two pumping stations of the water company.

——— Marl deposits, bowlders, and bedrock geology of the Ann Arbor quadrangle: Ann Arbor folio (No. 155), Geol. Atlas U. S., U. S. Geol. Survey, 1906.
Discusses origin and extent of marl.

SALISBURY, R. D., and CHAMBERLIN, T. C. See Chamberlin and Salisbury.

SCHERMERHORN, L. Y., Physical characteristics of the northern and northwestern lakes: Am. Jour. Sci., 3d ser., vol. 33, 1887, pp. 278-284.
Gives area, watershed, length of shore lines, depth and character of bottom, rainfall, run-off, and fluctuations in level of each of the Great Lakes.

SCHOOLCRAFT, H. R., Narrative journal of travels in 1820 through the northwestern regions of the United States from Detroit to the Mississippi, Albany, 1821, 419 pp.
Reviews explorations by Marquette, Joliet, La Salle, Hennepin, La Hontan, Charlevoix, Alexander Henry, Carver, Hearne, and McKenzie in the Great Lakes region and the country to the north. Describes with much accuracy the shore features of Lake St. Clair, St. Clair River, west side of Lake Huron, both sides of Lake Michigan, and part of the south shore of Lake Superior, calling attention to the small extent of the rock outcrops and the universal presence of granitic and hornblendic rocks even on high points like Mackinac Island. Notes buried timber between sand deposits and blue clay near the head of St. Clair River, and remarks that the drift deposits or alluvium may be composed of several distinct formations.

——— Production of sand storms and lacustrine beds by causes associated with the North American Lakes: Proc. British Assoc, vol. 12, 1842, pp. 42-44. Also Am. Jour. Sci., vol. 44, 1843, pp. 368-370.
Describes encroachment of dunes on fertile land.

SCOVELL, J. T., Geology of Vigo County, Ind.: Twenty-first Ann. Rept. Dept. Geology and Nat. Res. Indiana, 1897., pp. 546-565.
Discusses topography, ancient channels, recent valleys, glacial deposits, and soils.

——— Terraces of the lower Wabash: Proc. Indiana Acad. Sci., 1898, pp. 274-277.

——— Lake Maxinkuckee: Twenty-fifth Ann. Rept. Dept. Geology and Nat. Res. Indiana, 1900, pp. 233-247, 261-265.
Discusses the drainage basin, springs, flowing wells, topography, flora, marl, and mud deposits. Estimates age of lake to be between 8,000 and 12,000 years, from rate of deposition of marl.

——— Road material of a portion of western Indiana: Thirtieth Ann. Rept. Dept. Geology and Nat. Res. Indiana, 1905, pp. 571-653.
Discusses a preglacial channel followed in part by Wabash River, the terraces along the river, and the distribution of workable gravels on uplands.

SHERZER, W. H., Geological report on Monroe County, Mich.: Geol. Survey Michigan, vol. 7, pt. 1, 1900, 240 pp.
Discusses the glacial geology and lake history and the pre-Pleistocene formations; also treats climate, soils, water supplies, road materials, etc.

——— Ice work in southeastern Michigan: Jour. Geology, vol. 10, 1902, pp. 194-216.
Argues that the rock scorings show records of each of the great ice invasions.

——— Water supplies of Wayne County, Mich.: Water-Supply Paper U. S. Geol. Survey No. 182, 1906, pp. 48-78.
Devotes much space to the underground supplies; also discusses water power and public water supplies for Detroit and other cities.

——— Geological report on Wayne County, Mich.: Pub. Michigan Geol. and Biol. Survey No. 12, Geol. ser. 9, 1913, 388 pp., 32 pls., 22 figs.

SHEPHERD, FOREST, Remarks on a bowlder mass of native copper from the southern shore of Lake Superior: Am. Jour. Sci., 2d ser., vol. 4, 1847, pp. 115-116.

——— Observations on the drift furrows, grooves, scratches, and polished surfaces of the rocks of Lake Superior: Am. Jour. Sci., 2d ser., vol. 4, 1847, pp. 282-283.

SHUFELDT, G. A., On the subterranean sources of the waters of the Great Lakes: Am. Jour. Sci., 2d ser., vol. 43, 1867, pp. 193-197.
Suggests that much water may reach the lakes by underground courses.

SIEBENTHAL, C. E., Quaternary deposits of the Bedford limestone region: Twenty-first Ann. Rept. Dept. Geology and Nat. Res. Indiana, 1896, pp. 300-303.
Outlines the glacial boundary and extent of small glacial lakes, and reports bearing of striæ near the glacial boundary.

——— Topography, Pleistocene deposits, and drainage of the hydraulic limestone area in southern Indiana: Twenty-fifth Ann. Rept. Dept. Geology and Nat. Res. Indiana, 1900, pp. 359-364.

SPENCER, J. W., Preglacial outlet of the basin of Lake Erie into that of Lake Ontario with notes on the origin of our lower Great Lakes: Proc. Am. Phil. Soc, vol. 19, 1882, pp. 300-337; Second Geol. Survey Pennsylvania, Rept. Q4, 1881, pp. 357-404.
Brings evidence of a deep channel leading from Lake Erie past Cayuga and Seneca, Ontario, into Dundas Valley and Lake Ontario.

——— Notes on the origin of the Great Lakes of North America: Proc. Am. Assoc. Adv. Sci., vol. 30, 1882, pp. 131-146.
Discusses relative value of theories concerning geological valleys, glacial erosion basins, atmospheric and fluvial erosion (obstructed by drift), and the need for some oscillation of level.

——— Warping of the earth's crust in relation to the origin of the basins of the Great Lakes: Am. Naturalist, vol. 21, 1887, pp. 168-171.
Infers a warping at the upper rapids of the Mississippi (probably incorrectly) and argues that warping extends into the Great Lakes region.

——— Lake beaches at Ann Arbor, Mich.: Am. Geologist, vol. 2, 1888, p. 62.
A brief note stating that his observations confirm those by Dr. Wooldridge. See also Wooldridge, C. W.

——— The St. Lawrence basin and the Great Lakes: Canadian Rec. Sci., vol. 3, 1888, pp. 232-235; Am. Geologist, vol. 2, 1888, pp. 346-348; Am. Naturalist, vol. 23, 1889, pp. 491-494.
Reports the discovery of the ancient course of St. Lawrence River, the origin of the basins of the Great Lakes, the establishment and dismemberment of Lake Warren, the outlet of the Huron-Michigan-Superior Lake into Lake Ontario by the Trent Valley, and states that Lake Erie is the youngest of all the Great Lakes.

——— Notes on the origin and history of the Great Lakes of North America: Proc. Am. Assoc. Adv. Sci., vol. 37, 1889, pp. 197-199.
Discusses same subjects as the last-cited paper.

——— High continental elevation preceding the Pleistocene period: Bull. Geol. Soc. America, vol. 1, 1890, pp. 65-70.
Cites the Great Lakes depressions and deep canyons near the continental border in support of high elevation.

——— Ancient shores, bowlder pavements, and high-level gravel deposits in the region of the Great Lakes: Bull. Geol. Soc. America, vol. 1, 1890, pp. 71-86.
Discusses characteristics of ancient shore lines in the Great Lakes region, bowlder pavements and fringes on lake borders and valley slopes, gravel deposits under the till (termed "buried beaches"), unclassified buried gravels (so-called osars and kames), other ridges thought to be beaches, and gravel plains.

——— Origin of the basins of the Great Lakes of North America: London Quart. Jour. Geol. Soc, vol. 46, 1890, pp. 523-531.
Reiterates views expressed in 1882 and gives a few additional data.

——— Deformation of the Algonquin beach and birth of Lake Huron: Am. Jour. Sci., 3d ser., vol. 41, 1891, pp. 12-21.
Describes a beach which appears on the borders of Lakes Huron, Michigan, and Superior, and names it the Algonquin. Briefly considers the differential uplift and changes of outlet which it has experienced.

——— High-level shores in the region of the Great Lakes and their deformation: Am. Jour. Sci., 3d ser., vol. 41, 1891, pp. 201-211.
Describes the several beaches bordering the Huron-Erie basin from the Forest up to the Maumee and notes the amount of warping they have undergone. Refers to "higher coast lines" preceding the Maumee, but thinks some of these may be kames and osars and that all need further investigation.

——— Post-Pliocene continental subsidence versus glacial dams: Bull. Geol. Soc. America, vol. 2, 1891, pp. 465-476.
Notes the evidence of recent occupancy by water at higher levels than the present Great Lakes; considers glacial dams less likely to have caused the retention of waters than a depression to sea level.

——— A review of the history of the Great Lakes: Am. Geologist, vol. 14, 1894, pp. 289-301.
Treats briefly the several topics discussed in his earlier papers, with references to the work of other investigators.

——— The geological survey of the Great Lakes: Proc. Am. Assoc. Adv. Sci., vol. 43, 1895, pp. 237-243.
Similar in scope to last paper.

——— How the Great Lakes were built: Pop. Sci. Monthly, vol. 49, 1896, pp. 157-172.
Similar in scope to last two papers.

——— An account of the researches relating to the Great Lakes: Am. Geologist, vol. 21, 1898, pp. 110-123.
Similar in scope to last three papers, though dealing more especially with what each writer has contributed.

——— The Falls of Niagara: Rept. Geol. Survey Canada for 1905, pub. 1907, 490 pp., 43 pls., 30 figs.
Considers the water power and rate of recession and the various topographic and geologic features along the gorge that have affected the recession; also the variations in the volume of water occasioned by the discharge of the upper lakes at certain times by other outlets than Niagara, and the tilting that has deflected the discharge to Niagara.

SPENCER, J. W., L'évolution des chutes du Niagara: La Géographie, vol. 22, 1910, pp. 105-115.
Briefly treats the history of the Great Lakes basins, the work of the falls, and their probable duration. For the first time admits that glacial dams are a factor in the history and development of the Great Lakes.

——— Relation of Niagara River to the glacial period: Bull. Geol. Soc. America, vol. 21, 1910, pp. 433-440.
Thinks that St. Davids buried channel leading northwest from the whirlpool, referred by some geologists to an interglacial Niagara, is preglacial, since it contains a remarkably full series of glacial and interglacial beds, the earliest of which seems likely to be at least as old as the Illinoian drift.

——— Relative work of the Falls of Niagara: Bull. Geol. Soc. America, vol. 21, 1910, pp. 441-446.
Computes the recession more precisely than earlier students, but does not greatly modify earlier results. Places the mean annual rate of recession of the American fall at 0.27 foot and of the Canadian fall at 4.2 feet.

——— Interruption in the flow of the Balls of Niagara in February, 1909: Bull. Geol. Soc. America, vol. 21, 1910, p. 447.
Gives photographs to show a great reduction in volume due not to an ice jam but to the anchoring of ice in a low-water stage in very cold weather.

——— On the focus of-postglacial uplift north of the Great Lakes: Jour. Geology, vol. 19, 1911, pp. 57-60.
Shows, by combining triangles in the region of uplift bordering Lake Ontario and Georgian Bay, that the uplift converges to a focus in about latitude 49° N. and longitude 76° W.

——— Postglacial earth movements about Lake Ontario and the St. Lawrence River: Bull. Geol. Soc. America, vol. 24, No. 2, 1913, pp. 217-228, 1 fig. (map), pp. 714-715.

——— Relationship of the Great Lake basins to the Niagara limestone: Bull. Geol. Soc. America, vol. 24, No. 2, 1913, pp. 229-232, 1 fig. (map).

——— Relationship between terrestrial gravity and observed earth movements of eastern America: Am. Jour. Sci., 4th ser., vol. 35, 1913, pp. 561-573, 1 map.

——— Postglacial changes of level versus recent stability of the Lake region of America: Rept. British Assoc. Adv. Sci., Eighty-second Meeting, 1913, pp. 476-477.

——— Outline of the evolution of the Falls of Niagara; contrast with the falls of the Zambesi (private publication), 1913, 8 pp., 2 pls. (map).

STIMHOX, WILLIAM, On the deep-water fauna of Lake Michigan: Am. Naturalist, vol. 4, 1871, pp. 403-405.
Records the occurrence of marine crustaceans in the deep part of Lake Michigan; mentions absence of marine shells in the beaches of the lake; suggests that the lake communicated with the ocean in such a way that salt water invaded the lower portion while the surface waters were sufficiently fresh to permit the existence of lacustral species of mollusks. See also P. R. Hoy.

STUNTZ, G. R., On some recent geological changes in northeastern Wisconsin: Proc. Am. Assoc. Adv. Sci., vol. 18, I870, pp. 200-207.
Suggests a differential elevation in the Great Lakes region with northeastward uplift. See also Gilbert and Moseley.

SUTTON, GEORGE, The gold-bearing drift of Indiana: Proc. Am. Assoc. Adv. Sci., vol. 30, 1882, pp. 177-185.
Notes gold in Dearborn, Ohio, Ripley, Jennings, Jackson, Brown, Morgan, Montgomery, and Warren counties, hid. Thinks ice moved northwest to southeast, scattering the gold through these counties, a view which is out of harmony with the evidence from moraines and other features.

TAYLOR. A. E., Road materials of portions of central and eastern Indiana: Thirtieth Ann. Rept. Dept. Geology and Nat. Res. Indiana, 1905, pp. 315-356, 359-387, 389-437, 439-496, 501-570. Road materials of southwestern Indiana: Thirtieth Ann. Rept. Dept. Geology and Nat. Res. Indiana, 1905, pp. 969-970, 974-975, 981-982, 986-987, 990-1001.
Each paper discusses briefly, county by county, the occurrence of workable deposits of gravel, the limestone, and oilier sources of road material.

TAYLOR, F. B., The highest old shore line on Mackinac Island: Am. Jour. Sci., 3d ser., vol. 43, 1892, pp. 210-218.
Describes highest old beach on island and near mainland and recognizes it as Spencer's Algonquin Beach. Classifies beaches as earlier, faint, and fragmentary in southern part of Great Lakes basins, and later, stronger, and continuous in northern part, all being inclined to south more or less. Ascribes former to ice-dammed lakes, latter to marine submergence.

——— A reconnaissance of the abandoned shore lines of Green Bay [Michigan and Wisconsin]: Am. Geologist, vol. 13, 1894, pp. 316-327.
Describes old beaches between Sheboygan, Wis., and north end of Green Bay in Michigan. The shores rise to the north.

——— A reconnaissance of the abandoned shore lines of the south coast of Lake Superior: Am. Geologist, vol. 13, 1894, pp. 305-383.
Describes old beaches between Sault Ste. Marie and Duluth. Suggests name "Nipissing" for lowest and strongest. Regards, probably wrongly, the gravel deposits back of Marquette, 590 feet above the lake, as a beach. Says beach back of Houghton at 410 feet is probably the Algonquin. Supposes Nipissing beach to pass below lake level at Duluth.

TAYLOR, F. B., The limit of postglacial submergence in the highland east of Georgian Bay: Am. Geologist, vol. 14, 1894, pp. 273-289.
Describes beach which defines upper limit of submergence between Barrie and Trout Creek, Ontario, identifies it as Algonquin, and estimates its age (by laminated clay in deltas) at not less than 2,500 years. Regards it (wrongly) as marine and as correlative of upper marine deposits in the lower St. Lawrence Valley.

——— The ancient strait at Nipissing: Bull. Geol. Soc. America, vol. 5, 1894, pp. 620-626.
Gives descriptive details of beaches near North Bay, Ontario, on Lake Nipissing. Thinks the higher ones mark marine waters (a view now abandoned). Traces the lowest or Nipissing over a col to Trout Lake into head of temporary outlet of upper Great Lakes to Ottawa River.

——— Changes of level in the region of the Great Lakes in recent geological time: Am. Jour. Sci., 3d ser., vol. 49, 1895, pp. 69-71. (Letter in reply to J. D. Dana.)
Discusses marine hypothesis of northern beaches. Later abandons views favoring marine origin. (See letter to Am. Geologist, vol. 17, 1896.)

——— The Munuscong Islands (Michigan): Am. Geologist, vol. 15, 1895, pp. 24-33.
Says that hills north of Hessel, Mich., showed as small islands in Lake Algonquin. Gives details of beaches near Gros Cap and on Mackinac Island. Shows rate of rise of Nipissing and Algonquin beaches from Petoskey to Sault Ste. Marie.

——— The second Lake Algonquin: Am. Geologist, vol. 15, 1895, pp. 100-120, 162-179.
Discusses the lakes bounded by the Nipissing Beach and gives a history of the changes of altitude of its plane, based on data of the preceding reconnaissances. [The name "second Lake Algonquin" was replaced later by "Nipissing Great Lakes."] Gives quite fully the facts relating to Nipissing Beach as then known. Discusses change of outlet from North Bay, Ontario, to Port Huron, Mich., and its effect on history of St. Marys, St. Clair, Detroit, and Niagara rivers. Says this epoch of the lakes was synchronous with the maximum of marine Champlain submergence in the lower St. Lawrence. Entertains hypothesis of marine origin for higher northern beaches.

——— Sketch of the Quaternary history of the Great Lakes: Public Occurrent, weekly, Fort Wayne, Ind., vol. 1, No. 2, Dec. 14, 1895.
Gives a popular account of the Great Lakes, embodying the results of a reconnaissance on north coast of Lake Superior in 1895 disproving existence of straits to Hudson Bay. Includes also results of reconnaissance of the Mattawa and Ottawa valleys in which the last position of the ice dam holding Lake Algonquin was found. First uses name "Nipissing Great Lakes."

——— The Nipissing beach on the north Superior shore: Am. Geologist, vol. 15, 1895, pp. 304-314.
Reviews and discusses A. C. Lawson's "Sketch of abandoned strands of Lake Warren." Finds that Nipissing Beach rising to northeast is recognizable in Lawson's descriptions.

——— Preliminary notes on studies of the Great Lakes made in 1895: Am. Geologist, vol. 17, 1896, pp. 253-257.
Gives brief summary of results of reconnaissance of north coast of Lake Superior and of Mattawa and Ottawa valleys. States reasons for final rejection of marine hypothesis of northern beaches of upper lakes, which had been held up to this time. Finds evidences in the Ottawa Valley of ice dam which held Lake Algonquin and of rush of waters where outlet opened through this valley.

——— Notes on the Quaternary geology of the Mattawa and Ottawa valleys: Am. Geologist, vol. 18, 1896, pp. 108-120.
Gives additional details of glacial history of the two valleys.

——— Correlation of Erie-Huron beaches with outlets and moraines in southeastern Michigan: Bull. Geol. Soc. America, vol. 8, 1897, pp. 313-317.
Describes Imlay and Ubly outlets and eastern part of Grand River outlet. Shows relations of the several beaches and moraines to these and to other less important spillways, and discusses character of water-laid moraines. Introduces names of Lake Whittlesey, Lake Saginaw, and Duplain Beach, and limits name of Lake Warren.

——— A short history of the Great Lakes: Dryer's Studies in Indiana geography, pp. 90-110, Inland Pub. Co., Terre Haute, 1897.
Discusses in popular form changes of outlet, altitude, area, and depth in the glacial lakes incident to the recession of the ice sheet. Discusses also the relation of lake history to Niagara Falls and to the Champlain marine submergence in the lower St. Lawrence Valley.

——— Moraines of recession and their significance in glacial theory: Jour. Geology, vol. 5, 1897, pp. 421-466.
Notes existence of 15 moraines of recession of Wisconsin age between Cincinnati and Mackinac. Discusses their theoretical significance and the light they throw on the behavior of the ice sheet. Argues that the position of water-laid moraines shows that ice lobes stood with solid fronts in lakes and calved few icebergs. Data have been slightly modified by later investigations, the time found for glacial recession being probably too great.

——— The Nipissing-Mattawa River, the outlet of the Nipissing Great Lakes: Am. Jour. Sci., 4th ser., 1897, pp. 208-218. Abstract in Am. Geologist, vol. 20, 1897, pp. 65-66.
Describes a recent great river in the Mattawa Valley. Conditions of erosion showed to be in some respects exceptional, but time allowed for its work is probably too long.

TAYLOR, F. B., Notes on the abandoned beaches on the north coast of Lake Superior: Am. Geologist, vol. 20, 1897, pp. 111-128.
Gives details of reconnaissance made in 1895. Identifies Nipissing beach and shows it rising to the northeast. The Algonquin beach, doubtfully identified, appears to be nearly horizontal.

——— The Champlain submergence and uplift, and their relations to the Great Lakes and Niagara Falls (abstract): Rept. British Assoc. Adv. Sci. for 1897, pp. 652-653.
Discusses interrelations generally and with special reference to their bearing on the history of Niagara Falls.

——— Some features of the recent geology around Detroit (abstract): Proc. Am. Assoc. Adv. Sci., vol. 46, 1898, pp. 201-202.
Gives details of old beaches, moraines, and river conditions around Detroit. Discusses drowned condition of tributaries of St. Clair-Detroit River and of the west end of Lake Erie.

——— The great ice dams of Lakes Maumee, Whittlesey, and Warren: Am. Geologist, vol. 24, 1899, pp. 6-38.
Discusses the lakes named, with special reference to proofs of existence of the great ice dams which retained them.

——— Surface geology of Lapeer County, Mich.: Rept. State Board Geol. Survey Michigan for 1901, pp. 109-117.
Gives sketch of surface geology based on unfinished field work. Maps moraines and glacial drainage, including Imlay outlet, in the region of the reentrant angle between the Huron and Saginaw lobes.

——— Relation of Lake Whittlesey to the Arkona beaches: Seventh Ann. Rept. Mich. Acad. Sci., 1905, pp. 29-36.
Argues that features in St. Clair County, Mich., show that the Arkona beach or beaches antedate the Belmore, though at a lower level, and that a readvance of the ice marked by the Port Huron morainic system raised the lake level and formed Lake Whittlesey, whose discharge was through the Ubly outlet.

——— Pleistocene deposits of southwestern Ontario: Summary Rept. Canada Geol. Survey, 1908, pp. 102-111; 1909 pp. 164-167.
Gives results of leveling and incidental investigations on Algonquin and Nipissing beaches made with assistance of J. W. Goldthwait, R. C. Jacobson, and W. A. Johnston. The 1909 report describes the glacial formations in the central part of the peninsula and in an area on the north shore of Lake Erie between Simcoe and the mouth of Grand River.

——— A review of the Great Lakes history with special reference to the deformation of the ancient water planes (abstract): Science, vol. 27, 1908, pp. 725-726.
Chiefly considers the deformation in the beaches of the Michigan and Huron basins, which has since been largely worked out by spirit leveling; considers other basins briefly.

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CHAPTER II.
PHYSICAL FEATURES.

By FRANK LEVERETT.

The region embraced in this monograph includes the deep basins of Lakes Michigan and Huron as well as the country between them and its southward continuation to the glacial boundary. These basins and their bordering lowlands controlled the courses of glacial movement to a marked degree, while the highlands between the basins checked the flow of the ice and gave it a lobate border.

TOPOGRAPHY.

ALTITUDE.

MICHIGAN.

The greater part of the bed of Lake Michigan lies between 300 feet above and 300 feet below sea level, a narrow strip, trending north and south about in the direction of the axial movement of the ice from latitude 44° 20' to latitude 44° 40', reaching the latter depth.

In the Huron basin, where only a few square miles are down to sea level, the deep portion trends northwest and southeast nearly at a right angle to the general direction of ice movement from the Labrador center; it lies, however, more nearly in line with the probable course of ice movement from the high land north of Lake Superior at an early stage of glaciation. Saginaw Bay, the large southwest arm of Lake Huron, although in the line of axial movement from the Labrador center, is a very shallow body of water, its bed being more than 500 feet above sea level. The strong flow of ice through the Saginaw basin was probably induced by topographic conditions on the eastern side of Lake Huron. Ice moving into the Lake Huron basin from Georgian Bay would naturally have passed on directly into the Saginaw basin.

The altitude of the rock surface in Michigan is greatest in a strip leading from the "thumb," or Huron-Saginaw upland, southwest toward the corners of Michigan, Indiana, and Ohio. The culminating points, situated in Jackson and Hillsdale counties, exceed 1,100 feet above sea level, and the drift knolls there reach nearly 1,300 feet. This high tract formed the belt of separation between the Saginaw and Huron-Erie ice lobes. The rock surface maintains a high altitude southward only to the southern part of Hillsdale County, Mich., but a prominent belt of very thick drift, rising above the 1,000-foot contour, continues south westward for some distance into northeastern Indiana. It was heaped up between the Saginaw and Huron-Erie lobes.

On the northwest border of the Saginaw basin is an elevated tract, the Michigan-Saginaw upland, which embraces the highest points of the drift surface in the southern peninsula. As shown by the contours of the topographic map[1] of Michigan (Pl. I) about one-fourth of the area north of latitude 44° has an altitude between 1,100 and 1,200 feet, and one-fourth has an altitude of 1,200 to 1,700 feet. The descent from 1,100 to 900 feet is abrupt, giving the area between 1,100 and 1,200 feet a shelf-like or table-land appearance. This shelf, however, is not due to the configuration of the underlying rock, for so far as known the rock in this region nowhere rises 900 feet above sea level; it is a great accumulation of drift, averaging perhaps 400 feet in depth, which was banked up between the converging ice lobes from the Michigan, the northern Huron, and the Saginaw basins.

[1]First published in Water-Supply Paper U. S. Geol. Survey No. 182.

The average altitude of the entire southern peninsula of Michigan (not including the beds of the Great Lakes) is estimated to be 835 feet. The range in altitude is from 573 to 1,710 feet. The highest points are morainic knobs a few miles southeast of Cadillac in Sherman Township, Osceola County, and the lowest are on the border of Lake Erie. As planimeter measurements of the bedrock contours (see Pl. II) made by W. F. Cooper, of the Michigan Geological Survey, show an average altitude of 554 feet, an average thickness of nearly 300 feet of drift is indicated. The bedrock ranges from a little below sea level to fully 1,100 feet above.

INDIANA.

The average altitude of Indiana has been estimated by Gannett[1] to be 700 feet and by Gorby[2] to be 800 feet; the estimate by Gorby, being based more largely on field observations, is perhaps the closer approximation. The altitude ranges from 314 feet at the mouth of the Wabash to 1,285 feet on the morainic hills in southern Randolph County.

Outside of the prominent drift belt in the northeastern counties only one large area in Indiana rises above 1,000 feet. This is in the eastern part of the State, chiefly in Wayne and Randolph counties, and is due to the rock surface, which reaches fully 1,100 feet and bears morainic knolls that rise above 1,200 feet. It is in this area that the reentrant between the Miami and East White lobes is found. Only here and in the "thumb" of Michigan do rock elevations seem to have had much influence on ice movements; the low basins now occupied by the Great Lakes were the features which had greatest control.

In northern Indiana and in nearly all of the southern peninsula of Michigan the rock surface is entirely concealed beneath the thick glacial deposits. In southern Indiana, however, a succession of rock formations from the Ordovician to Pennsylvanian is exposed from east to west. (See Pl. III.) These formations trend from west of north to east of south about parallel to the western or main branch of the Cincinnati axis. As they vary greatly in their power to resist weathering and erosion, they have given rise to a series of troughs or basins separated by ridges and highlands. These, however, have exerted but little influence on the flow of the ice or the outline of the ice border.

The hills in the more resistant formations rise to a somewhat regular elevation that suggests a peneplain, and a few hills in the softer formations reach nearly the same altitude. Most of the divides in the friable rocks of the southwestern part of the State, however, are 50 to 150 feet lower than the level of the suggested peneplain, and only isolated hills rise to its level. Some of the hills of friable rock carry deposits of bronzed gravel, presumably of Tertiary age, that antedate the erosion of the formation elsewhere; for example, two hills north of Princeton, Ind., some knobs bordering White River near Shoals, and other knobs in Washington County[3] carry a little bronzed gravel similar to the Tertiary gravel of southern Illinois.

[1]Gannett, Henry, Thirteenth Ann. Rept. U. S. Geol. Survey, pt. 2,1893, p. 289.

[2]Gorby, S. S., Sixteenth Rept. Dept. Geology and Nat. Hist. Indiana, 1891, p. 217.

[3]Cox, E. T., Third Rept. Geol. Survey Indiana, 1872, p. 138. Leverett, Frank, Eighteenth Ann. Rept. U. S. Geol. Survey, pt. 4, 1897, p. 433; also Mon. U. S. Geol. Survey, vol. 41, 1902, p. 111. Fuller, M. L., and Ashley, G. H., Ditney folio (No. 84), Geol. Atlas IT. S., IT. S. Geol. Survey, 1902, p. 6. Blatchley, W. S., Thirtieth Ann. Rept. Dept. Geology and Nat. Res. Indiana, 1905, p. 936.

RELIEF.

INDIANA.

Throughout much of the drift-covered portion of Indiana the surface is monotonously smooth, both on slopes of 10 to 20 feet to the mile and on nearly dead-level surfaces. Many moraines also are inconspicuous.

Sharply morainic tracts with prominent knob and basin topography are found mainly in three localities. The largest and most prominent is in the northeastern part of the State and covers a considerable part of Steuben, Lagrange, Noble, and Kosciusko counties and parts of Dekalb, Whitley, Wabash, Miami, and Fulton counties. In this tract are many knolls 30 to 50 feet high and a few 75 to 100 feet or more; among them are numerous basins containing lakes and marshes. The second large morainic tract sweeps around the head of Lake Michigan and fills much of the interval between the lake and the Kankakee marsh. Its knolls rarely reach 50 feet in height, but they are closely aggregated and so interspersed with basins that the expression is in striking contrast to the bordering plains. The third area is in southern Randolph, southeastern Delaware, and northern Henry counties, in the reentrant between the East White lobe and the Miami lobe. As already noted, this reentrant occurs in the highest part of Indiana, where the altitude was influential in preventing the extension of the ice so far south as on bordering lower tracts. The area, which is 6 to 10 miles wide and 30 miles long, is not only filled with sharp knolls inclosing deep basins and sloughs but is also thickly strewn with bowlders.

The morainic tracts mentioned were formed at the last or Wisconsin stage of glaciation. The exposed surface of the older or Illinoian drift sheet presents only a few developments of ridged drift. Some of these, however, are prominent, reaching a height of 50 to 150 feet, as, for example, Chestnut Ridge in Jackson County and Mount Auburn in Shelby County.

The few eskers in Indiana-are but 10 to 25 feet in height and 3 miles or less in length. No drumlins have been observed, and few kames are found outside of the strong morainic belts.

MICHIGAN.

Strong moraines are numerous in the southern peninsula of Michigan. They rival and some of them far exceed the strongest in Indiana, reaching heights of 300 to 400 feet or more. In the southeastern part of the State some of the moraines of the Wisconsin stage override a basal ridge of pre-Wisconsin drift, and possibly they form only the upper part of the high land northwest of the Saginaw basin. The bulk of the drift accumulation may have been developed in pre-Wisconsin stages of glaciation. The plane-surfaced portions of the drift of Michigan are chiefly on the borders of the peninsula and in a broad belt extending southwestward from the Saginaw basin beyond Lansing; the latter, however, is interrupted by a few morainic ridges with gently undulating surface. A considerable part of the plains was covered by glacial lake waters.

Eskers are numerous on the slope that rises toward the south from the Saginaw basin. (See Pls. VIII-XI.) Their height is commonly only 20 to 30 feet, but their very steep sides make them conspicuous.

Drumlins are numerous in Antrim and Charlevoix counties (figs. 2 and 3), and a few are found in Emmet, Cheboygan, and Alpena counties. They range in height from 60 to 70 feet down to barely perceptible ridges.

The lines of glacial drainage and the outlets of the large glacial lakes are conspicuous, some of them being many times the size of the valleys excavated by the postglacial streams. This is very apparent where a stream passes from a modern or postglacial valley into a line of glacial drainage. The shores of the glacial lakes are on the whole inconspicuous, though characteristic enough to have been recognized and traced by pioneer students. The Algonquin and Nipissing shores are much more conspicuous than those of the earlier lakes, and probably those lakes were longer lived.

Sand dunes are conspicuous on the border of Lake Michigan in Lake, Porter, and Laporte counties, Ind., the highest having an altitude of about 200 feet. The wind which formed them derived its material partly from the abandoned shores and beds of the glacial Lake Chicago and partly from the present shore of Lake Michigan. The largest are built up from the present shore, those connected with the shore of Lake Chicago being usually less than 50 feet in height. Low sand ridges 10 to 20 feet high in the Kankakee and Tippecanoe drainage basins in northern Indiana and on the borders of the White, East White, Eel, and Wabash valleys in central

and southwestern Indiana, are apparently the product of wind action.

In Michigan sand dunes are prominent along much of the shore of Lake Michigan. They are highest at the river deltas, where many of them rise 200 feet above the lake. A few low dunes occur on the border of Saginaw Bay. Dunes have been formed in places on the sandy outwash plains among the moraines, and sand storms occur even now when high winds sweep across cleared fields in these plains.

DRAINAGE.

LAKES.

INDIANA.

Numerous small lakes in the northern part of Indiana occupy depressions in the drift surface. The largest, Turkey or Wawasee in Kosciusko County, has an area of only 5.66 square miles. Few cover more than 1 square mile. The greatest depth, 121 feet, is found in Tippecanoe Lake in Kosciusko County, but depths of 50 or more feet are found in many others. In the northwest part of the State several shallow lakes are shut in between dune belts or beaches of Lake Michigan and those of its predecessor, Lake Chicago. Numerous shallow ponds and lagoons lie in the alluvial bottoms of the large rivers in the southwestern part of the State. In Dubois County, near Jasper and Ireland, some conspicuous though shallow lakes, having areas of several hundred acres each, stand in the line of preglacial valleys that have been only partly filled by drift deposits. So far as known these are the only lakes in the State that antedate the Wisconsin ice invasion. They are nearly filled by muck and aquatic vegetation and have recently been greatly reduced in area by artificial drainage.

The number of lakes and ponds in the State represented on the county maps in Baskin, Forster & Co.'s State atlas is 683, of which 156 are in the alluvial bottoms and are transitory. Some of those in the depressions of the glacial drift are nearly filled by vegetal growth and some have been drained to a marshy condition by artificial ditches. There remain probably less than 400 which are too deep to be drained. The following table, obtained in large part from the report by Blatchley and Ashley on the lakes and marl deposits of Indiana,[1] gives a list of the more important lakes with their areas, altitudes, and depths:

Lakes of Indiana having an area of 1 square mile or more.

Name.	County.	Area.	Altitude above sea level.	Maximum depth.
		Sq. miles.	*Feet.*	*Feet.*
Turkey or Wawasee	Kosciusko	5.66	862	68
Maxinkuckee	Marshall	2.97	734	89
James	Steuben	2.62	[b] 1,260	87
Wolf [a]	Lake and Cook	2.50	580	14
Bass	Starke	2.23	[b] 720	32
Tippecanoe	Kosciusko	1.61	[b] 850	121
Crooked	Steuben	1.47	.....	30
Manitou	Fulton	1.39	[b] 760	49
George	Lake	1.35±	.....	...
Lake of the Woods	Marshall	1.25	[b] 825	.....
Cedar	Lake	1.17	680	20
Duchemin	Laporte	1.17±	[b] 770	...
Fish	Steuben	1.15	910	68
Little Eagle	Kosciusko	1.10	[b] 850	...
Webster	do	1.06	[b] 855	43

[a] Partly in Cook County, Ill.

[b] Determined by barometer.

MICHIGAN.

In the southern peninsula of Michigan lakes are present in every county except three at the head of Saginaw Bay; they are scarce, however, in several other counties in the plain southwest of this bay and in the plain bordering Lakes Erie, St. Clair, and the southern part of Lake Huron. They range in area from a few acres to 31 square miles, the largest being Houghton Lake, in Eos-common County. The number is not known, for in some of the northern counties the best maps yet published represent only a part of them. Many land-survey plats show only those crossed by section or quarter-section lines and give measurements of only a few of those crossed; consequently the outline and extent of few are correctly set forth. The inaccuracies of the land-survey plats have been repeated in county atlases and other maps.

[1] Twenty-fifth Ann. Rept. Dept. Geology and Nat. Res. Indiana, pp. 31-321, 1901.

The lakes nearly all occupy depressions in the surface of the glacial deposits, some of them being in the moraines and others in the outwash aprons. Many in the latter areas are without surface outlet. The depth of few lakes is known, but that of those in the moraines and outwash aprons appears to be as great as that of lakes of corresponding size in the moraines and outwash aprons of northern Indiana—40 to 100 feet or more. As in Indiana, many of the lakes contain large deposits of marl 40 feet or less in depth. A few lakes along the shore of Lake Michigan are shut in by dunes and are shallow; a few in Monroe County are in sink holes in the limestone; and a few in Alpena and Presque Isle counties are in sink holes or in rock basins. Long and Grand Lakes in the counties last mentioned are situated at the base of rock escarpments but owe their existence, at least in part, to drift obstruction.

The following table contains a list of 81 lakes (all that have an area of a square mile or more), with their approximate altitudes and their areas as estimated from the county maps in the Tackabury atlas. They aggregate 390 square miles and probably embrace half the inland-lake area in the peninsula. Most of the altitudes have been determined by aneroid barometer or estimated from altitudes of neighboring railway stations. A few stand near the level of Lake Michigan and a few, as indicated in the table, have been determined by spirit level.

Lakes in the southern peninsula of Michigan having an area of 1 square mile or more.

Name.	County.	Area.	Altitude above sea level.	Name.	County.	Area.	Altitude above sea level.
		Sq. miles.	*Feet.*			*Sq. miles.*	*Feet.*
Houghton	Roscommon	31	*a b* 1,125	Rush	Huron	2	595
Pine	Charlevoix	29	580	Coldwater	Branch	2	*a* 1,000
Mullet	Cheboygan	28	594	Marble	...do	1.8	*a* 1,000
Torchlight	Antrim	27	592	Cedar	Alcona	1.5	*a* 595
Burt	Cheboygan	25	596	Manistee	Kalkaska	1.5	*a* 1,185
Black	...do	18	*a* 615	East Twin	Montmorency	1.5	*a* 1,210
Higgins	Roscommon	15	*a* 1,160	West Twin	...do	1.5	*a* 1,210
Hubbard	Alcona	13	*a* 700	Grass	Benzie	1.5	*a* 825
Crystal	Benzie	11	585	Big Star	Lake	1.5	*a* 850
Elk	Antrim	10	589	Chippewa	Mecosta	1.5	*a* 1,050
Glen	Leelanau	9	*c* 597	Cass	Oakland	1.5	930
Carp	...do	8.5	*c* 589	Austin	Kalamazoo	1.5	870
Grand	Presque Isle	8.5	*d* 636	Crooked	Barry	1.5	925
Long	Alpena	8	*d* 690	Diamond	Cass	1.5	880
Muskegon	Muskegon	7	580	Klinger	St. Joseph	1.4	875
Walloon or Bear	Charlevoix-Emmet	7	*a* 685	Turtle	Montmorency	1.3	*a* 850
Douglass	Cheboygan	5.5	*a* 700	Odessa	Ionia	1.3	825
Crooked	Emmet	5	600	Orchard	Oakland	1.3	920
Intermediate	Antrim	5	607	Corey	St. Joseph	1.3	875
Portage	Manistee	4	580	Paw Paw	Berrien	1.3	630
Long	Grand Traverse	4	*c* 836	Sage	Ogemaw	1.25	*a* 850
Big Sable	Mason	4	582	Silver	Grand Traverse	1.25	875
Big Charn	Wexford	3.5	1,280	Au Sable	Oceana	1.25	580
Platte	Benzie	3.5	*a* 595	Fremont	Newaygo	1.25	780
Missaukee	Missaukee	3.5	*a* 1,210	Pierce	Emmet	1.25	620
St. Helens	Roscommon	3.5	1,150	Devil	Alpena	1.25	595
Tawas	Iosco	3	585	Reed	Kent	1.25	750
Portage	Crawford	3	1,130	Devil	Lenawee	1.25	1,050
Otsego	Otsego	3	1,270	Long	Genesee	1.2	*a* 900
Bear	Manistee	3	*a* 760	Crystal	Montcalm	1.1	*a* 800
White	Muskegon	3	580	Lakeville	Oakland	1.1	*a* 975
Grass	Antrim	3	595	Long	Kalamazoo	1.1	870
Carp	Emmet	3	715	Crooked	Missaukee	1	1,240
Gun	Barry	3	*a* 720	Thumb	Charlevoix	1	*a* 1,000
Gull	Kalamazoo	2.75	*a* 850	Bass	Mason	1	580
Van Etten	Iosco	2.5	589	White	Oakland	1	*a* 1,020
Duck	Grand Traverse	2.5	*c* 819	Whitmore	Washtenaw	1	894
Green	...do	2.5	*c* 803	Portage	...do	1	851
Round	Antrim	2.5	589	Pine	Barry	1	*a* 900
Black	Ottawa	2.5	580	Wamplers	Lenawee	1	*a* 1,000
Little Clam	Wexford	2	1,280				

a Determined by aneroid barometer.
b Alexander Winchell gives this altitude as 1,170 feet.
c Spirit levels run by Prof. J. B. Davis, of the University of Michigan.
d Determined by Prof. A. W. Grabau, of Columbia University.
e Spirit levels run by J. J. Hubbell, chief engineer of the Manistee & Northeastern Railroad.

STREAMS.

PREGLACIAL DRAINAGE.

Concerning the course of preglacial drainage very little can be determined in a region with such great drift accumulations.

In Indiana borings from the vicinity of Lafayette westward have disclosed a preglacial valley, with a rock floor scarcely 300 feet above sea level, running westward a little north of Wabash River. The borings indicate that a deep valley leads into this from the north and another from the east, both joining it not far from the city of Lafayette. The one from the north probably carried the drainage of a considerable part of northern Indiana, and possibly was the line of discharge for the southern portion of the basin now covered by Lake Michigan.

A preglacial valley, which has been traced from Celina, Ohio, westward into northern Indiana and which passes near Geneva, Hartford, Marion, and Pern, probably belongs to the same system as that draining northern Indiana; in this valley the drift is nearly 400 feet thick, whereas on the interfluvial tracts on either side it is less than 100 feet thick. The presence of such valleys must be taken into account in estimating the thickness of drift.

In the southern peninsula of Michigan one of the most important preglacial valleys leads from the head of Saginaw Bay southwestward into Gratiot County and thence westward and northwestward to the Lake Michigan basin north of Ludington. (See Pl. IV.) It indicates a drainage from the Saginaw basin to the basin of Lake Michigan, as the floor becomes lower in passing westward from Saginaw Bay.

PRESENT-DAY DRAINAGE SYSTEMS.

The greater part of Indiana is tributary to the Wabash, itself a tributary to the Ohio; the southern end of the State is directly tributary to the Ohio through smaller streams; the northeastern part drains through the Maumee to Lake Erie and the northwestern part largely through the Kankakee to the Illinois, though a narrow strip drains to Lake Michigan. The southern peninsula of Michigan drains entirely to the Great Lakes, the western half to Lake Michigan, and the eastern half chiefly to Lake Huron and its arm, Saginaw Bay, though some small areas in the southeastern part drain to Lakes St. Clair and Erie and to St. Clair and Detroit rivers.

The boundaries between the several river systems fall mainly within the glaciated region and are largely determined by glacial accumulations. The only important water partings within the glaciated portion of Indiana which to any marked degree coincide with the elevated rock surfaces are in southern Randolph County between the headwaters of White River, a tributary of the Wabash, and those of Whitewater River, a direct tributary of the Ohio; but even here the water partings result only in a general way from the elevated rock surface, their precise position being determined by morainic accumulations. The water parting between the tributaries of the Wabash and the small tributaries of the Ohio in southern Indiana from the meridian of Salem westward is chiefly due to rock irregularities, for most of the small Ohio tributaries lie wholly in unglaciated territory; but from near Salem eastward the water parting is inside the glacial boundary and is only in a general way dependent on the rock surface.

In the southern half of Michigan the high altitude of the rock surface determines in a general way the divide between the westward drainage to Lake Michigan and Saginaw River and the eastward drainage to Lake Huron, St. Clair River, Lake St. Clair, Detroit River, and Lake Erie. In the remainder of the southern peninsula the water partings show little or no dependence on the rock surface.

DEVELOPMENT OF PRESENT DRAINAGE.

Some of the present drainage did not come into existence directly on the withdrawal of the ice. During the occupancy of the immediate basins of Lakes Michigan, Huron, and Erie by the ice sheet the territory to the south was tributary to Mississippi River either through the Wabash and Ohio, the Kankakee and Illinois, or the Desplaines and Illinois. Lakes held between the ice and the present St. Lawrence-Mississippi divide discharged across the latter through large and well-defined outlets, that to the Wabash being known as the Fort Wayne or the Erie-Wabash outlet and that to the Desplaines as the Chicago outlet. Glacial lakes discharged also through outlets leading across the southern peninsula of Michigan, conspicuous among which were the Imlay, the Ubly, and the Grand River outlet.

Little of the present drainage within the glaciated portion of this region coincides for any great distance with the preglacial lines. Many of the streams are too shallow to reach the bottom of the glacial deposits, and those that have cut through them commonly encounter merely the crests of preglacial rock ridges; throughout the greater part of both Indiana and Michigan the beds of the present streams are above the tops of the rock ridges of the districts they traverse.

The drainage varies from a very immature stage, in which the streams have scarcely begun to open a channel, to a well-defined, widely branching system with well-graded channels. Drainage within the glaciated region, however, is nowhere mature; in the Illinoian drift area much poorly drained surface remains even where channels are well graded; and in the Wisconsin drift area many of the stream channels themselves are immature and have numerous lakes along their courses.

In much of Michigan the development of surface drainage is proceeding very slowly, because the drift is sufficiently porous to rapidly absorb nearly all the rainfall. Many townships are wholly destitute of surface streams and are yet so well underdrained that the soil is not swampy. On the other hand, many tracts with clayey or impervious soil have plentiful surface drainage and yet remain swampy in parts because their soil absorbs so small a percentage of the rainfall.

THICKNESS OF THE DRIFT.

The region covered by this monograph probably embraces the largest area of thick drift in North America. The greater part of the southern peninsula of Michigan and the northern and central portions of Indiana are so deeply covered that wells seldom reach the rock. The average thickness of drift in the southern peninsula of Michigan, as determined by Cooper's planimeter measurements, already noted, is about 300 feet, and an equally great thickness prevails over several counties in northern Indiana. It is probable that on parts of the southern peninsula of Michigan nearly 1,000 feet of drift is present. In Indiana the greatest thickness reported is about 500 feet (at Kendallville).

The geologic map of the southern peninsula of Michigan (Pl. II) shows the rock altitude by bedrock contours. On part of the western side of the State, from Ludington northward about to Frankfort, the rock surface lies about at sea level and to reach it wells near the level of Lake Michigan penetrate over 600 feet of drift.

In Indiana the distribution of the belts of thick drift (Pl. IV) is in part due to the filling of preglacial valleys, notably the Whitewater, the East White, and the Wabash. In the central and northern parts of the State, however, the drift is 100 feet or more thick on the preglacial interfluvial tracts and 300 to 500 feet along the lines of preglacial drainage.

CHAPTER III.
PRE-WISCONSIN DRIFT AND ASSOCIATED DEPOSITS.

By FRANK LEVERETT.

LIMIT OF GLACIATION.

The mapping of the glacial boundary or drift limit in Indiana and Kentucky (see Pls. V and VI) has been brought to its present state through the work of various individuals. In several of the early reports of the Indiana Geological Survey notes on the drift limit are given in connection with more detailed descriptions of the subjacent rock formations. Somewhat later G. F. Wright[1] extended his observations on the limit of glaciation westward from Ohio into Illinois with results sufficiently full to warrant a map setting forth the approximate limit, though he did not, as appears from later studies, give the exact boundary in all districts. The present writer subsequently reconnoitered the border of the drift both in Kentucky and Indiana and presented the results in Monographs XXXVIII and XLI of this Survey. This reconnaissance, it is believed, fixed the limit of glaciation within 1 to 5 miles of its precise position. Owing to the attenuated and patchy condition of the drift near the border he found more precise work difficult. Subsequent to the publication of his reports, Fuller[2] and Clapp[3] made a more detailed study of the glacial boundary in southwestern Indiana, determining - its character between East White and Wabash rivers more accurately than has been done in any other part of Indiana.

The border of the well-defined drift deposits enters Indiana from Illinois near the mouth of Wabash River and follows Big Creek and its north or main branch northeastward into northwestern Vanderburg County, whence it runs slightly north of east, entering Gibson County south of Haubstadt. It then runs northward to near Francisco and then eastward past Oakland into Pike County, but within a short distance beyond turns northward and crosses Patoka River and the divide between Patoka and White rivers near the meridian of Petersburg. Here its position is obscured by the deposits of a small glacial lake, Lake Patoka, which covered a considerable area in northeastern Pike and northwestern Dubois counties. The lake extended as far southeast as Jasper, but the ice apparently ended just south of East White River.

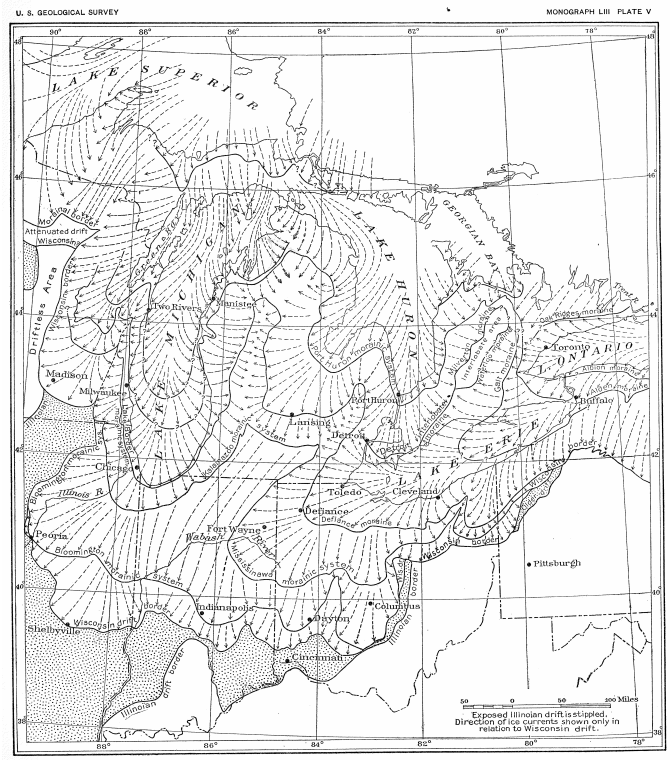
Beyond the area of Lake Patoka the border of the glacial drift crosses to the north side of East White River near Portersville and takes a course slightly east of north to Loogootee, keeping a short distance west of East White River. It then trends northward near the line of Daviess and Martin counties past Burnes and Scotland and into Greene County to Newark, whence, as determined by Siebenthal for the Indiana Survey, it goes northeastward across southeastern Owen and northwestern Monroe counties to the edge of Morgan County.

Here the glacial boundary is at its northernmost point in Indiana. Its course thence southeastward to Ohio River has been less accurately traced. It turns somewhat abruptly southeastward across the northeast corner of Monroe County to Needmore in Brown County and passes north of Marshall to Mount Liberty in eastern Brown County. Thence it runs southward near Brownstown, Mount Sidney, Little York, Vienna, and Henryville to the Ohio opposite Louisville. It seems to follow the Ohio, without crossing into Kentucky, for several miles above Louisville, and it does not leave the Ohio Valley to strike back into Kentucky until it reaches Bedford, Ky. East of Bedford it remains on the Kentucky side of the Ohio for about 60 miles, or until far past the eastern border of Indiana. It crosses the Ohio into the State of Ohio about 25 miles above Cincinnati.

[1]The glacial boundary in western Pennsylvania, Ohio, Kentucky, Indiana, and Illinois: Bull. U. S. Geol. Survey No. 58, 1890.

[2]Fuller, M. L., and Ashley, G. H., Ditney folio (No. 84), Geol. Atlas U. S., U. S. Geol. Survey, 1902.

[3]Fuller, M. L., and Clapp, F. G., Patoka folio (No. 105), Geol. Atlas U. S., U. S. Geol. Survey, 1904.



[PLATE V. Diagrammatic representation of the outline of the ice border at several successive positions and the direction of ice movements in connection with each position]

Fuller[1] and Clapp[2] have found that stratified drift in local patches occurs for several miles south of the limit given in Monograph XXXVIII and that a few drift pebbles occur still farther south. The distribution of these patches of stratified drift is not readily accounted for by the ordinary processes of stream deposition nor by the existence of ponded waters during their deposition. The evidence of an extension of the ice over this region of patchy stratified drift is far from conclusive and the explanation of these features must await further investigation. Cox,[3] many years ago, reported the presence of a granite bowlder on a hillside above the village of Carrsville in Livingston County, Ky., still farther outside the limits of well-defined glacial deposits than the gravels noted by Fuller and Clapp.

ILLINOIAN AND PRE-ILLINOIAN (?) DEPOSITS.

COMPLEXITY OF THE BOUNDARY.

The boundary just delimited is apparently that of the Illinoian stage of glaciation. In its vicinity in Indiana and at some points some distance back from it certain features are apparent which suggest some complexity of glacial movement and deposition. Whether they are the product of an oscillating ice front in a single stage of glaciation or represent two distinct stages of glaciation remains to be determined.

Early reports of the Indiana Geological Survey contain a few scattered records of the existence of a black mucky soil interbedded with the marginal drift. As the soils reported are near the glacial boundary, where the upper sheet is practically coterminous with the lower one, they may be interpreted as having been formed during a slight recession of the ice and covered by a fresh advance. Other features, however, suggest greater complexity. Nuggets of copper and certain associated rocks of the Lake Superior region are present in the drift deposits of central Indiana nearly to the glacial boundary and farther east in western and central Ohio, and suggest an ice movement from the Lake Superior region. They apparently occur in the basal portion of the drift, and thus may underlie the drift from the Labrador field.

BURIED SOIL.

A special effort was made in the summer of 1903 to determine the character of the interval represented by the buried soil of the marginal portion of the drift, but the definite results hoped for were not fully obtained. Examinations of exposures in the hilly counties in central Indiana developed the fact that flat tracts inclosed among the hills are the best localities for the preservation of the buried soil. Of these tracts the most extensive and, on the whole, the most satisfactory is an area of 50 to 60 square miles in southern Putnam and northern Owen counties, known as the “flatwoods.” It is underlain largely by Mississippian limestone, which has a nearly level surface preserved apparently in tabular form. This condition of the underlying rock has much to do with the flatness of the surface. The following beds are exposed in the numerous ravines and road gradings:

Representative section exposed in ravines in southern Putnam County.

	Feet.
Surface silt or clay, white, pebbleless; apparently a correlative of the main loess deposit of the Mississippi basin	4– 6
Soil, black, gummy, or gumbo, with quartz pebbles, representing apparently the Sangamon interglacial soil	1– 3
Till, brown, generally with deeply weathered surface, apparently of Illinoian age	3–15
Gumbo, black, changing to blue or gray below; generally containing a few pebbles	1– 8
Till, brown, extending to bottom of ravines, in places changing to blue; exposed	5–10

Twenty feet or more of the black mucky material is reported beneath the upper sheet of till in certain wells in the region, but no exposure exceeding 8 feet was found in ravines. In one exposure the till immediately below the lower soil is blue, and in nearly all it is only slightly oxidized; indeed, in only one was it found to be highly weathered. This exposure, which is in a ravine crossing from T. 13 N. into T. 12 N., R. 3 W., about 2 miles east of Cloverdale, near the corner of secs. 33, 34, 3, and 4, shows a buried mucky soil 6 to 8 feet thick, underlain by till that is redder and apparently more weathered than the till above. The buried muck beds are perhaps as conspicuous in these flat areas among the hills of central Indiana as are those found between the Illinoian and Kansan drift sheets of southeastern Iowa, but they are not underlain by the highly weathered and oxidized till sheet that characterizes the upper part of the Kansan drift in Iowa. The results of the study, therefore, leave the occurrence of a long interval of deglaciation in doubt.

[1]Fuller, M. L., and Ashley, G. H., op. cit.

[2]Fuller, M. L., and Clapp, F. G., op. cit.

[3]Tenth Ann. Rept. Geol. Survey Indiana, 1878, p. 106.

MINERALS IN THE DRIFT.

COPPER.

In the absence of other and conclusive evidence of direct invasion the nuggets of native copper in the basal portion of the drift should not be given great weight. It is possible that the copper was transported into districts farther north by ice movement across the Superior region from the Patrician field and was then brought into this region by the Labrador ice sheet from points where it chanced to cross the deposits of the earlier ice sheet. This area in south-central Indiana is in a reentrant angle between the Illinois lobe and the lobe covering eastern Indiana and western Ohio and is likely to have received contributions from both. The path of the Illinois lobe is such as to bring deposits from far north if not from the outcrops of copper-bearing rocks in the eastern end of the Superior basin. So far as this particular area is concerned, therefore, the sufficiency of the evidence of an invasion from the Superior region is doubtful.

GOLD.

With the nuggets of copper have been found small amounts of gold, and also a few diamonds and chunks of lead. The copper, diamonds, and lead seem to have been derived from the base of the drift; the gold, however, comes from considerable heights above the base as well as low down, as has been proved by the observations made by R. L. Royse, of Martinsville, Ind., during the sinking of a shaft 5 miles northwest of Martinsville in sec. 24, T. 12 N., R. 1 W., on the slope of a large gravel hill which presumably was formed as a closing feature of the ice occupancy of this region. The shaft was started 65 feet below the highest point of the hill and was sunk to a depth of 135 feet without entering rock. The material was panned for its entire depth and yielded gold at all levels from top to bottom. The following record of the shaft was obtained from Mr. Royse:

Section of Royse gold shaft, 5 miles northwest of Martinsville, Ind.

	Feet.
1. Gravel and cobble, coarse, with a few bowlders, extending to level of base of gravel hill, waterbearing near bottom	32
2. Reddish clayey cemented crust with much iron	3
3. Clay, blue, gummy	6
4. Sand, coarse, and fine gravel, nearly dry	30
5. Sand, fine, with but little water	40
6. Gravel, reddish, with light streaks	14
7. Clay, deep blue	10
	135

The “colors” or flakes of gold were most abundant in 1 and 4. The fine sand (5) contained only minute “points” of gold, but the reddish gravel which underlies it showed flakes as coarse as those in 1 and 4.

DIAMONDS.

Drift diamonds have been found southeastward from the neighborhood of Minneapolis Minn., across Wisconsin, Michigan, and Indiana into Ohio. Hobbs[1] discussed their distribution

[1]Hobbs, W. H., The diamond field of the Great Lakes: Jour. Geology, vol. 7, 1899, pp. 375-388.

in the light of glacial movements and concluded that they may have all been transported by the Labrador ice field from the vicinity of the south end of Hudson Bay or from the district between Hudson Bay and Lake Superior, from which there is clear evidence of movement toward the southwest and south to the localities where the diamonds have been found. But though the movements of the Labrador ice field at both the Wisconsin and the Illinoian invasions would favor such a derivation for the diamonds, or at least for those found between the Wisconsin driftless area and Cincinnati, it should be remembered that like the copper they may also have been transported by ice from the Lake Superior region, if that ice extended southeastward through the upper Great Lakes basins into Indiana and Ohio prior to the extension of the Labrador ice field into the same region. Such a movement may have brought them from the Patrician ice field recently described by Tyrrell.[1] (See p. 24.) It is necessarily difficult to work out the movements of such an ice sheet in territory where its deposits were subsequently overridden and concealed by the drift of the Labrador ice, yet such an earlier movement may contain the key to the home of the diamonds. If the lower of the two old drift sheets of Indiana and Illinois pertains to the movement from the Superior region and only the upper one to the Labrador field, the great extent of the diamond-bearing drift from northwest to southeast may indicate the course of transportation of the diamonds instead of the terminal line to which they were transported, and their home may be north of Lake Superior rather than northeast of it.

TOPOGRAPHY.

The contrasts in topography displayed by the pre-Wisconsin drift are fully as great as those displayed by the Wisconsin drift. Indeed, the pre-Wisconsin includes some of the sharpest drift ridges of the State and some of the smoothest plains. The ridges and knolls of this older drift are less systematically distributed and are less definitely confined to moraines or otherwise connected with the ice border than those in the newer drift. However, as far north as southern Michigan, pre-Wisconsin ridges of morainic type are distributed in belts concentric with the great basins.

The flat surface of the greater part of the pre-Wisconsin drift, not only in Indiana but also in Ohio and Illinois, seems to indicate that the retreating ice border did not make prolonged halts such as characterized the recession of the ice border in the Wisconsin stage. Even .along its southern edge the knolls and ridges of the older drift can scarcely be said to form a moraine, for they are loosely distributed and level surfaces predominate. Scattered over the older drifts kames or sharp gravelly knolls rise either singly or in clusters to heights of 20 to 50 feet or more above bordering nearly plane tracts; many of them stand in low areas along the line of preglacial valleys or on valley slopes, and in such situations some of them reach heights of over 100 feet.

As already indicated, a few ridges of drift several miles in length have been developed. One such ridge, in Morgan County, along Indian Creek southeast of Martinsville, is scarcely one-half mile wide and is 50 to 100 feet or more in height. Another, within the limits of the later or Wisconsin drift, in southwestern Shelby County, is known as Mount Auburn Ridge, the village of Mount Auburn being on its crest; it is about 9 miles in length, 2 miles in width, and 75 to 150 feet in height, with an irregular surface on which knolls rise abruptly 50 to 75 feet. The mantle of later or Wisconsin drift is remarkably thin, the thickest deposit noted being only 15 feet in depth. A third conspicuous ridge is Chestnut Ridge in Jackson County, first described by Cox[2] and also discussed at some length by the present writer in Monograph XLI; its length is about 8 miles, its width but little more than one-half mile, its height 50 to 170 feet, and its surface somewhat hummocky and irregular. Wells on the ridge show part of it to carry a coating of till 50 feet or more in depth, but the greater part seems to be gravel and sand.

[1]Tyrrell, J. B., Hudson Bay exploring expedition, 1912: Twenty-second Ann. Rept. Ontario Bur. Mines, pt. 1, 1913.

[2]Sixth Ann. Rept. Geol. Survey Indiana, 1874, pp. 42, 56-57.

All these ridges appear to be made up mainly of waterworn assorted material and should perhaps be classed as kame moraines, though they are not parallel with the neighboring parts of the glacial boundary. The Mount Auburn Ridge trends north-northeast and south-southwest, directly toward the glacial boundary instead of parallel with it. The trend of the other two ridges diverge only slightly from that of the neighboring glacial boundary, and they are each within about 5 miles of the limits of the well-defined drift sheet. Mount Auburn Ridge appears to have been formed at the junction of converging ice currents, for it stands back of a sharp bend or reentrant in the glacial boundary.

Detailed mapping of the knolls of this earlier drift has not been attempted. In the hilly districts along the drift border it is difficult correctly to interpret some of the hills, for some which had been supposed to have a rock nucleus have been proved by boring to be made up very largely of drift. Even the detailed studies by Fuller and Clapp in the quadrangles in southwestern Indiana were not carried far enough to warrant a separation of all the drift hills from those with a rock nucleus.

Ridges of pre-Wisconsin drift some distance inside the limits of the Wisconsin, though known by borings to be present, are so deeply buried under the later drift that little is known concerning their topography. Those in southeastern Michigan appear to be broad, massive belts rather than sharp ridges. They will be considered in connection with the discussion of the later drift.

STRUCTURE OF THE PRE-WISCONSIN DRIFT.

COMPOSITION.

The glacial deposits found outside and also beneath the Wisconsin drift for some distance inside its limits consist very largely of a clayey till oxidized to a brownish color near the surface but becoming a blue-gray unoxidized till at a depth of 20 feet or less. The till as a rule is thickly set with small stones and contains some bowlders, though few large ones; often several exposures must be examined to find one that exceeds a foot in diameter. Yet some 4 to 6 feet in diameter have been found clear out to the limits of glaciation.

The character of this drift sheet varies to some extent in accord with the underlying rocks, yet in other respects it is constant. Thus the calcareousness of the till is striking even in districts where it overlies sandstone. The rock constituents include limestone derived from the formations along the path traversed by the ice. The character of the drift sheet varies with the drainage conditions along the ice border; thus gravelly and sandy material is scarce over much of the area of exposure in western and eastern Indiana but is more common in central Indiana. In Owen, Morgan, Johnson, and Brown counties, Ind., sand and gravel form the bulk of the drift knolls and ridges as well as the filling in the preglacial valleys. The attenuated border in Pike and Gibson counties, as indicated by Fuller and Ashley,[1] contains considerable sand and gravel, but the preglacial valleys of that region, except the Ohio and Wabash, are largely filled with silt or fine sand. Records obtained in several counties in southwestern Indiana show that the pebbly glacial material forms only a thin capping of the surface.

The silt filling is attributable to deposition in ponds caused by ice blocking the mouths of valleys that drained northwestward, and hence were favorably situated for receiving the turbid discharge from the ice sheet but not for receiving the coarser outwash. These silt deposits were eventually covered by the advancing ice as far out as the limits of glaciation. Their calcareousness in a sandstone region, such as that of most of the valleys thus filled, shows clearly that the ice sheet contributed the material. Wells in these silts yield decidedly harder water than those sunk in the rock formations of the region, and this condition of the water has furnished an index of the nature of the silts at many points where they have not been exposed to view.

[1]Ditney folio (No. 84), Geol. Atlas U. S., U. S. Geol. Survey, 1902, p. 3.

Valleys with this sort of filling are conspicuous in Posey, Gibson, Vanderburg, Pike, Dubois, Davis, Clay, and Vigo counties and occur in other counties. In places the silts underlie glacial ridges, a conspicuous instance being a ridge that rises 30 to 50 feet above the railway station east of Fort Branch. This ridge is composed of loose-textured reddish drift carrying considerable sand and a moderate number of bowlders and coarse pebbles The wells along it enter what is termed “blue mud” at about the level of the base of the ridge and continue in it for 40 to 60 feet until they reach rock.

South of the west-flowing parts of East White and White rivers in Dubois, Pike, Gibson, Posey, and Vanderburg counties there is very little typical till. The clayey parts of the drift carry few pebbles and exceedingly few bowlders. Both the clayey and the sandy deposits indicate that lake or water action was so combined with glacial action as to influence nearly all the glacial deposits. The uplands carry only scanty glacial material, a thickness of 10 feet being rare, but the valleys contain 75 to 100 or more feet, including the silt deposits above described.

The general presence of till in the district north and west of White River puts it in contrast with the district to the south and east, and the amount of drift on the uplands is much greater, reaching depths of 20 to 60 feet or more.

The deposits in some preglacial valleys are described as black mud, though their color is usually blue or gray. The most conspicuous occurrences are in the valleys of Eel River and White River in Clay and Greene counties, and are possibly flood-plain deposits antedating the glacial invasion, though the absence of samples makes it difficult to judge.

INTERBEDDED DEPOSITS.

BURIED SILT OR LOESS.

In scattered exposures in the southwestern counties of Indiana fossiliferous silt very similar to the loess that overlies the till occurs beneath or is interbedded with the till. It may, however, be of small extent and may not represent widespread conditions such as prevailed during the main loess deposition. Several occurrences were examined in 1902 by M. L. Fuller and the writer.

Loess was found interbedded with till about 5 miles south of Hazleton in eastern White River Township, Gibson County. The overlying till is of the ordinary clayey type characteristic of the Illinoian drift sheet and is thickly set with pebbles. The underlying deposit seems to have fewer pebbles but is apparently glacial. The loess is gray and contains many fossils. The exposures were not sufficient to determine whether both the drift sheets and the included loess belong in the Illinoian stage or whether the lower drift belongs in an earlier stage of glaciation. The lower sheet appears to be fully as much oxidized as the upper. The loess outcrops in a gully at the roadside and appears to be 12 to 15 feet thick.

Buried loess was also found on the north bluff of the Ohio about 16 miles below Rockport, Ind., in sec. 4, T. 8 S., R. 7 W., where it is separated from the surface loess by a bed of pebbly clayey alluvium. The following section was observed along the newly graded road leading down to the Ohio Valley from the residence of Mr. Deyss on the bluff:

Section of Ohio River bluff at Deyss private road, sec. 4, T. 8 S., R. 7 W.

	Feet.
Loess, brown, loose textured	11
Clay, brown, slightly pebbly, becoming gray near base	14
Loess, gray, very thickly set with fossils	15
Clay, sandy, of marbled brown color, containing pebbly layers	13
Gravel, bronzed, apparently redeposited from the preglacial gravels outcropping in the bluff farther up the Ohio	17
	70

Scarcely 100 yards east of this road the bluff showed material change, as appears in the following section:

Section of Ohio River bluff 100 yards east of Deyss private road.

	Feet.
Loess, brown, loose textured	15
Clay, white, close textured	6
Clay, sandy, with layers of pebbles, not bronzed	13
Gravel, coarse, not bronzed	3
Gravel, bronzed, in cemented bed	1
Gravel, bronzed, uncemented	31
	69

In passing from the exposure last given westward to the wagon road the upper part of the bronzed gravel gives place to the sandy marbled-brown clay with pebbly layers about as a rock formation gives place to a drift deposit where the drift appears in the lee of a rock cliff in glaciated districts. The fossiliferous loess of the first exposure is not represented in the second and appears, therefore, to be a local deposit. Veatch[1] has called attention to other sections in this vicinity somewhat different from either of these and as difficult to interpret.

BURIED SOIL.

The occurrence of two drift sheets separated by a black soil or humus-stained gummy clay is most common in Putnam and Owen counties. Indeed, the present writer was unable to learn of any instances of it in the southwestern counties, the black material in the latter region being usually beneath all the glacial deposits. The same is true in most places in southeastern Indiana. This soil in Putnam and Owen counties was discussed by Collett[2] in an early report, as follows:

Wells to the number of 8 or 10 in the village [Quincy] at a depth of 15 to 30 feet pierce a black mucky soil containing brush, trees, leaves, grass, etc. This unctuous clay is characteristically lacustral. It is underlaid with quicksand and fine glacial gravel.

One of the wells in the village gave the following exhibit:

Section in Quincy well.

	Ft.	in.
Soil, black	1	8
Clay, white and gray, with crawfish pipes, with little sand, no pebbles	10	0
Clay, blue, with pebbles	3	0
Clay, black, mucky, with brush and plant remains	3	0
Hardpan and fine pebbles	3	0
Gravel, coarse, and bowlders (depth unknown)	3	0
	23	8

The trunks found in the above were of trees 4 to 5 inches in diameter, generally crushed or broken to pieces. The insertion of the branches was opposite or alternate like fir or ash and the rings of growth were compressed and fine, as if subject to a cold climate.

The present writer obtained records of wells near Quincy that passed through much more black mucky clay than is reported in the above section. In L. M. Combs's well, one-half mile east of the village, it extends from 14 to 28 feet below the surface; in G. W. Raikes's well, 2 miles west, it extends from 13 to 31 feet; and in O. W. Raikes's well, a short distance farther west, it extends from 8 to 40 feet. In each of these wells water-bearing gravel and sand underlie the black muck. Another well with a large amount of the black mucky clay was made by Samuel Beman 1½ miles northeast of Cataract, in the midst of the preglacial valley of Eel River. Its record, as interpreted by exposure in neighboring ravines, is as follows:

Record of Beman well near Cataract, Ind.

	Feet.
Clay, surface, including white clay and gumbo	14
Till, sandy and pebbly, of reddish brown color (Illinoian)	12
Clay, black, termed barnyard muck by owner	24
	50

[1]Jour. Geology, vol. 6, 1898, pp. 264-268.

[2]Collett, John, Seventh Ann. Rept. Geol. Survey Indiana, 1875, p. 319.

The well mouth is about 150 feet above Eel River (below the falls) where the stream reenters its old valley; it is therefore probable that the drift extends 100 feet below the bottom of this well. Mr. Beman states that the muck became rather sandy and yielded water toward the bottom of the well but held its black color. The well has been in use many years and the water appears to be of good quality.

In the southeastern part of Owen County, occupying the highest land between Spencer and Ellettsville, is a level tract known as the Flatwoods, which has been examined and reported upon by C. E. Siebenthal.[1] It is 2½ miles wide and 6 miles long. The southeastern end apparently is at the limits of glaciation. It carries an alternation of clay and sand beds with buried wood, and is thought by Siebenthal to have been occupied by a small glacial lake. He gives the following well record as typical of the region:

Record of well in Flatwoods district in sec. 31, T. 10 N., R. 2 W.

	Feet.
Soil and clay	17–18
Embedded logs	1
Clay	8
Gravel, waterworn	1
Clay, blue, sticky	8
Limestone.	

Collett[2] gives the following section in the same region:

Record of well in Flatwoods district in SE. ¼ sec. 26, T. 10 N., R. 3 W.

	Feet.
Soil, black, mucky	8
Sand and fine gravel	6
Quicksand, blue, sticky, with logs, sticks, and leaves	8
Associated gravel and sand deposits.	

GRAVEL AND SAND DEPOSITS.

Heavy deposits of gravelly drift in the vicinity of Spencer rise 150 feet or more above the village and extend nearly 100 feet below its level. The gravel is in places cemented into a firm conglomerate that outcrops like a ledge in the hillside. The cross-bedding in an exposure one-half mile northeast of Spencer indicates a stream flowing southward. The gravel there fills a preglacial valley leading into White River at Spencer from the north. Except in the vicinity of White River there are no conspicuous deposits of sand and gravel in Owen County, the drift back from the river being generally clayey.

Gravel and sand occur principally in Morgan, Johnson, Brown, and southwestern Shelby counties, as these counties stand immediately north of the great reentrant angle in the glacial boundary. It is probably because of this interlobate position that kames and gravelly deposits are more abundant here than in districts east or west. In eastern Morgan County gravel deposits abound from Indian Creek valley northward to White River. The gravel knolls or kames appear not only outside the border of the Wisconsin drift but for some distance inside it. Some of the latter apparently received only a thin coating of the later drift and were modified remarkably little by the readvance of ice. In western Morgan County gravel knolls or kames are present, but are far less numerous than in the eastern part, much of the drift being a clayey or sandy till. It is in one of the prominent kames in this part of the county that the gold shaft noted on page 64 was sunk. Flat-surfaced gravelly deposits of considerable extent occur in the valleys of this county and have been penetrated by wells to depths of about 100 feet before entering rock. These deposits along White River may be, in part, of Wisconsin age, but on some of the tributaries of the river they are known to be outside the limits of the Wisconsin sheet. In this connection it may be remarked that valleys in northern Monroe and Brown counties which are outside the limits of the Wisconsin outwash carry deposits of gravel and sand, which, in the several forks of Salt and Bean Blossom creeks, form terraces lying 30 feet or more above the streams. In these valleys, as in the gulches of central and southern Morgan County, gold and a few diamonds have been found.

[1]Twenty-first Ann. Rept. Indiana Dept. Geology and Nat. Res., 1897, pp. 301-302.

[2]Seventh Ann. Rept. Indiana Geol. Survey, 1875, pp. 333-334.

The gravel knolls of Johnson County, like those of eastern Morgan County, are in part within the limits of the Wisconsin drift and may be of pre-Wisconsin age, for the drift in them has a more weathered appearance than that of the surrounding deposits of Wisconsin age.

The Mount Auburn Ridge in southwestern Shelby County, as already indicated, is very largely of pre-Wisconsin drift. It has been penetrated by a few deep borings which show that the rock surface is considerably below its base. A well at the Mount Auburn schoolhouse, 198 feet deep, did not strike rock, passing largely through gravel, parts of which are cemented into conglomerate. Glacial conglomerate outcrops on the slopes of the ridge about a mile south of Mount Auburn. Collett reported that a well 1 mile west of Mount Auburn, on ground fully 100 feet lower than the village, struck rock at 108 feet. The following beds were penetrated:[1]

Record of well on Collins farm, 1 mile west of Mount Auburn, Ind.

	Feet.
Soil	4
Clay, yellow	6
Clay, sandy	10
Clay, bowlder	80
Sand, white	1
Sand and gravel	7
Limestone.	
	108

In Bartholomew County only the western edge lies outside the Wisconsin drift. Most of the surface is rugged, being a continuation of that in Brown County, with only a scanty coating of drift. There is, however, a narrow strip of lowland west of the East White Valley in which the drift has considerable depth.

Exposures west of Columbus along small tributaries of East White River show 50 feet of yellow till above blue till. Fifty-five feet of yellow pebbly clay and 5 feet of blue waxy clay above Devonian shale was found in a well on the farm of H. C. Harris, 1 mile west of Taylorville, very near the border of the Wisconsin drift; the greater part of the drift is thought to belong to the earlier ice invasion.

In the northeast part of Seymour, Jackson County, a gas boring passed through a black muck, apparently an old flood plain of East White River, at a depth of 55 to 65 feet, and other borings in the vicinity found the black muck at similar depths. No typical till appears to be present, the entire series of beds being water deposited.

Pleistocene beds penetrated in gas well at Seymour, Ind.

	Feet.
Sand, coarse	12
Sand or silt, very fine, almost a clay	43
Muck, black	10
Sand, coarse, with large amount of water	5
Clay, blue	5
	75

[1]Collett, John, Eleventh Ann. Rept. Indiana Dept. Geology and Nat. Hist., 1881, p. 68.

A well at Harvey Morris's, near the north end of Chestnut Ridge, reached a depth of 89 feet, of which the upper 20 feet was clay, with only a few pebbles, and the remainder fine sand, becoming pebbly near the bottom. A well near by at Jerry Anderson's, 95 feet in depth, penetrated 52 feet of clay, pebbleless at the top but becoming a stony till below, overlying 38 feet of gray sand, too fine to screen, which in turn overlies gravel in which the well terminates. At Mr. Wieneke's, near the highest point on the ridge and 140 feet above the bordering plain, a well 77 feet deep penetrated 33 feet of sandy loam and loose sand, underlain by 40 feet of reddish gravel and sand with clay admixture; the well terminates in coarse gravel. E. T. Cox made a well on the low part of the ridge, scarcely 50 feet above the bordering plain, which penetrated ordinary till, largely yellow, for 50 feet and then passed through 58 feet of sand, which became coarser and somewhat gravelly near the bottom. From these well data it appears that the ridge has a variable structure such as would be expected in a kame moraine.

Several counties in southeastern Indiana, namely, Franklin, Decatur, Jennings, Ripley, Dearborn, Ohio, Switzerland, Jefferson, Scott, and Clark, received, at the Illinoian stage of glaciation, a sheet of drift estimated to average less than 20 feet in thickness, though much thicker in valleys. The drift is composed mainly of clayey till and is covered to a depth of several feet by a white clay or compact loess. In some of the valleys tributary to Ohio River gravelly knolls appear and along the borders of the Ohio itself there is some gravelly drift of the earlier ice invasion.

In a few places black muck and driftwood, noted near the bottom of the glacial deposits, suggest, as do features in central and southwestern Indiana (p. 63), some oscillation of the ice border, if not two distinct ice advances. The present writer has not seen exposures of the buried soil or muck and underlying drift in southeastern Indiana and is hardly prepared to express an opinion as to the time relations. Buried soils are noted in several wells in reports of the Indiana Geological Survey.[1]

Gold has been found in notable amount in four of these southeastern counties. Haymond[2] reported its occurrence on Sein Creek and its tributaries and on Little Duck Creek in Franklin County. He also noted the discovery in that county of a mass of native copper weighing 6 pounds. Gold in the Laughery Valley near Hartford, in Ohio and Dearborn counties, was reported by Warder[3] and has been panned with profit for many years. A nugget of copper that weighed 26 pounds was found in Dearborn County near Weisburg. Borden[4] reports that gold has been panned on the south fork of Muscatatuck Creek in Jennings County and is widely distributed in that region.

DRAINAGE.

The drainage conditions attending the Illinoian ice invasion have not been clearly worked out. As noted above there was an aggradation of valleys in southwestern Indiana during or before the Illinoian stage of glaciation that involved the tributaries of the Ohio and Wabash as well as the main valleys. In the tributaries only fine sandy and clayey material is reported; in the main valleys gravelly material occurs, but does not seem to fill the entire width, for borings at and between

Evansville and Mount Vernon penetrate clay and fine sand similar to that in the tributaries.

[1]Third Ann. Rept. Indiana Geol. Survey, 1872, pp. 262, 344; Seventh Rept., 1875, p. 172.

[2]Haymond, Rufus, First Ann. Rept. Indiana Geol. Survey, 1869, p. 190.

[3]Warder, R. B., Third Ann. Rept. Indiana Geol. Survey, 1872, p. 420. Also Tenth Ann. Rep., 1878, pp. 106-107.

[4]Borden, W. W., Seventh Ann. Rept. Indiana Geol. Survey, 1875, p. 178.

In the Ohio Valley, on the border of southeastern Indiana, terraces of gravel derived from the Wisconsin drift show vigorous drainage at that late stage in the glacial epoch but furnish no clear evidence of vigorous drainage and gravel distribution down the valley during the Illinoian stage. In certain places along the valley at levels above the terraces of Wisconsin drift accumulations of gravelly materials were noted, but more commonly the valley was found to be filled with unassorted or very imperfectly assorted drift. The gravelly portions of this earlier drift are in many places cemented into a conglomerate, not only along the Ohio but also in the tributary valleys. The conglomerate at Split Rock, near Aurora, Ind., has long been known, and several other outcrops of conglomerate are discussed in the reports of the Indiana Survey. The writer's examination of the conglomerate at Split Rock led him to the conclusion that it was formed from a very stony till rather than from an ordinary gravel and cobble deposit. The matrix is largely calcareous clayey material instead of sand and this is what binds the stones together so firmly. The stones include bowlders measuring 2 feet or more.

PRE-WISCONSIN DEPOSITS BENEATH WISCONSIN DRIFT.

The pre-Wisconsin drift found some distance inside the limits of the Wisconsin is best distinguished from the Wisconsin if it consists of a clayey till. Generally this till is much more indurated than that of the overlying Wisconsin drift and is thus recognized by the drillers. In places, however, the induration is less general and may even be localized in certain layers between which are layers of loose material; in such places it is not so easy to determine when the drill enters the gravel or sand of the pre-Wisconsin. Probably a considerable number of the heavy deposits of drift in central and northern Indiana are of pre-Wisconsin age, but as they are largely sand and gravel or loose-textured material they can not easily be discriminated from the Wisconsin. Buried soils found in several of the central counties and still farther north in parts of Lagrange County, Ind., and Hillsdale County, Mich., at depths of 25 to 100 feet, probably mark the line of separation.[1]

In the vicinity of Ann Arbor, Mich., a considerable number of wells, situated along a prominent moraine that traverses the Ann Arbor quadrangle in a northeast-southwest course, enter, at a general depth of about 100 feet, though in places much less, an indurated till, which is thought to be pre-Wisconsin. A similar till is found along the Huron River valley in the vicinity of Ypsilanti, Mich., and is reported in many wells in that vicinity. Indurated till is present also in the plain east of the Ann Arbor quadrangle and on the eastern slope of the "thumb" of Michigan as far north as Sanilac County, several exposures having been found along streams and along the shore of Lake Huron. (See Pls. XII and XIII.) The appearance of the till in this district is strikingly similar to that of the Illinoian drift outside the Wisconsin drift in Illinois and Indiana. Though generally blue-gray it is traversed by seams and vertical joints or cracks filled with a brownish or deeply oxidized material as in the typical Illinoian outside the Wisconsin. Along the Lake Huron shore it is so indurated that small streams cascade over it as they might over a rock ledge, and at Ypsilanti it has the appearance of a reef in the river bed in which potholes and other features commonly found in rock formations are present. Such induration is seldom if ever found in the clayey parts of the Wisconsin drift. This fact and the local occurrence of soil between the indurated drift and the overlying softer material make it reasonably certain that the deposits are pre-Wisconsin. The presence of such drift in this region is to be expected from the fact that the ice sheet which formed the Illinoian drift must have passed across the southern peninsula of Michigan to reach Indiana and Illinois. For details of the pre-Wisconsin deposits of central and northern Indiana and southern Michigan see pages 63-67 289-290.

STRIÆ OUTSIDE OF THE WISCONSIN DRIFT.

Observations of striæ in Indiana outside the limits of the Wisconsin drift are confined to seven counties, Owen, Putnam, Parke, Clay, Vigo, Sullivan, and Greene, all in the southwestern part of the State. The stride bear from southward to eastward and, though somewhat divergent in the neighboring exposures, they all seem to fall in naturally with the movements of the Illinois glacial lobe, on the southern border of whose territory they appear. The following list comprises all which have come under the writer's notice:

Striæ outside of the Wisconsin drift in Indiana.

Location.	Bearing.	Observer.
PUTNAM COUNTY.		
Sec. 25, T. 13 N., R. 4 W	S. 4° E	Leverett.
Sec. 22, T. 13 N., R. 4 W	S. 5° E	Do.
Sec. 28, T. 13 N., R. 4 W	N.-S	Collett.
Near Cloverdale	S. 3° 40′ E.[a]	O. P. Jenkins.
OWEN COUNTY.		
Near Romona	S. 18° E	Siebenthal.
Sec. 32, T. 11 N., R. 3 W	S. 22° E	Leverett.
3 miles south-southwest of Vandalia	W.-E	Wright.
5 miles west from the preceding	S. 40°-50° E	Do.
Sec. 20, T. 9 N., R. 5 W	S. 18°-46° E	Collett.
CLAY COUNTY.		
Sec. 6, T. 11 N., R. 5 W	S. 26° 30′ E	Collett.
3 miles south-southwest of Bowling Green	S. 32° 10′ E	Do.
Sec. 1, T. 11 N., R. 6 W	S. 36° 50′ E	Do.
Do	S. 34° E	Leverett.
Sec. 19, T. 11 N., R. 5 W	S. 26° 30′ E S. 30° 35′ E	Collett. Do.
VIGO COUNTY.		
Sec. 3, T. 10 N., R. 9 W	S. 20° W	Scovell.
Sec. 36, T. 10 N., R. 9 W	N.-S	Do.
SULLIVAN COUNTY.		
2 miles southeast of Farmersburg	N.-S	Do.
GREENE COUNTY.		
1 mile northeast of Worthington	S. 72° E	Leverett.
Sec. 6, T. 7 N., R. 4 W	S. 80° E	Siebenthal.

[a] Corrected S. 0° 35′ W. by Jenkins in 1888 for magnetic variation. Of the other observations Mr. Leverett's have not been corrected and the rest are not known to have been.

[1]For an account of buried soils at Lagrange and Valentine, Ind., see Water-Supply Paper U. S. Geol. Survey No. 21, 1899, p. 26.

SANGAMON SOIL AND WEATHERED ZONE.

The Sangamon soil and weathered zone, formed on the surface of the Illinoian drift, has received attention in Monographs XXXVIII and XLI of this Survey, and little need be added concerning it. It separates the Illinoian drift by a very marked interval from the overlying loess and associated silt deposits. The writer has never observed the Illinoian drift to grade upward into the loess, either in Indiana or in the neighboring States, but has everywhere found it to be capped either with a deeply weathered zone or with a dark-colored soil.

These observations, however, are not in harmony with statements of several other geologists, who report gradations of the earlier or Illinoian drift into the overlying loess. The writer is of the opinion that these statements by his fellow workers are based on defective observations, for in two places occurrences claimed by two of his colleagues to illustrate such a transition were proved by a little excavating to afford good examples of an interval between the till and the loess, the surface of the till, being deeply weather-stained. In these cases the talus had been taken to be material in place. Where loess has crept down a slope over an eroded till surface from which the weathered zone had been removed, the inference might readily be drawn that no marked interval had occurred.

The interval between the Illinoian drift and the loess is generally marked in Indiana by a dark-brown coloration and by disintegration or weathering of the upper part of the till sheet. The deep brown changes gradually below to the ordinary brownish-yellow color of oxidized till and then to the unoxidized blue or gray till, but at the top it terminates abruptly at the base of the much fresher looking overlying silt. The dark-brown color extends usually to a depth of only 1½ to 3 feet, but leaching and some discoloration by weathering is generally noticeable to a depth of 6 to 8 feet. Where the surface of the Illinoian drift was flat or poorly drained prior to the loess or silt deposition, a black gummy soil is found, which contrasts sharply in color with the overlying yellowish-brown loess or the pale white clay or silt. The black soil has been seen frequently in all parts of the Illinoian drift outside the Wisconsin or newer drift from central Ohio to southeastern Iowa and occasionally inside the limits of the newer drift. The dark-brown weathered till surface is to be seen in nearly every newly made exposure in the well-drained districts. As the general thickness of the overlying silt in Indiana is but 5 to 10 feet on uplands and is even less on slopes, opportunities for observing the Sangamon weathered zone are very numerous.

POST-SANGAMON OR MAIN LOESS AND ASSOCIATED SILTS.

EXTENT AND DEPOSITION.

The weathered surface of the Illinoian drift and the outlying driftless territory in southern Indiana both bear a thin deposit of silt which is part of a practically continuous sheet that extends from Ohio westward beyond the Mississippi. In the vicinity of the main drainage lines it is loose textured and is commonly termed “loess.” On the interfluvial tracts it ranges from a deposit readily pervious to water to one very slowly pervious. The least pervious portion is of a pale color and is termed “white clay.”

The method of deposition of a large part of this silt is still in dispute and is one of the difficult problems of Pleistocene geology. Certain deposits of it along the main valleys, notably the marl-loess deposits of the Wabash, have been referred to fluvial action,[1] but generally along valleys as well as on interfluvial tracts the loess seems best explainable by wind action.

CHARACTER, OF THE LOESS.

Analyses of the loess show that it is composed mainly of silica, the percentage of the material being from about 60 up to fully 80 per cent. Alumina, which is the next in order of abundance, except perhaps in very calcareous parts such as the marl loess of the Wabash, ordinarily constitutes 10 per cent or more. The amount of oxide of iron is notable, ranging from about 1 per cent to more than 6 per cent in the analyses at hand. The following analyses of loess and associated silts in Indiana have been taken from reports of the Indiana Geological Survey:

Analyses of the loess and white clay in Indiana.

	1	2	3	4
SiO_2	79.77	72.87	71.20	60.00
Al_2O_3	9.85	11.25	18.56	
Fe_2O_3	3.39	6.75	1.34	
FeO			.13	.80
TiO_2	.70	.95	.88	1.00
MgO	.26	1.06	.52	
Na_2O	1.08	.39	1.26	
K_2O	2.05	2.26	.32	
CaO	.67	.69	.14	20.27
CO_2				15.03
H_2O	2.55	4.24	6.30	2.00
	100.42	100.46	100.67	100.00

1 and 2. White clay near Terre Haute at depths of 10 and 22 inches, respectively. Analyst, W. A. Noyes.
3. Near Princeton. Analyst, Robert Lyons.
4. Near New Harmony. Represents the marl loess. Taken from Owen's report for 1838.

A number of samples of loess and more compact silt collected by the writer in western and southern Illinois and mechanically analyzed under the direction of Milton Whitney, of the United States Department of Agriculture, show that the pervious loess contains a smaller percentage of very fine particles than the compact, but that it contains no more coarse particles. Considerable variation is shown, but the bulk of the deposit, in some samples as high as 75 per cent, consists of grains which fall between 0.05 and 0.01 millimeter, or 0.002 and 0.0004 inch in diameter. Few grains measure more than 0.1 millimeter, or 0.004 inch. Some soils in the loess contain a larger percentage of grains below 0.01 millimeter than subsoils, a feature which probably results in part from the greater disintegration of soil particles

and in part from the constant addition of very minute particles to the soil from dust carried in the atmosphere.

[1]Bull. Geol. Soc. America, vol. 14, 1903, pp. 153-176.

The thickness of the deposit in Indiana in few places exceeds 40 feet and is greatest along the Ohio and Wabash valleys. Within a short distance back from the bluffs of these valleys it decreases to 10 or 12 feet and over the greater part of the region is between 5 and 10 feet. On slopes it is very thin, or wanting, because of erosion.

It should be borne in mind that the loess here discussed is not the only deposit of its class in the Pleistocene series. In not a few places, some of which are in southwestern Indiana (see p. 67), loess occurs beneath or interbedded with the Illinoian drift. Loess is also found to a limited extent on the outer part of the Wisconsin drift in central and eastern Illinois and western Indiana. The loess just discussed is thicker as well as more continuous and widespread than are similar deposits at other geologic horizons.

PEORIAN OR POSTLOESSIAL SOIL AND WEATHERED ZONE.

In Indiana there are but few places where the loess or its associated silts have been found under the Wisconsin drift, and in these the weathered portion of the loess seems generally to have been incorporated in the Wisconsin drift, leaving only the lower part for inspection. Exposures near Greensburg were noted by Chamberlin[1] in his early explorations in that region, and the writer found others in that vicinity. Concerning these exposures Chamberlin writes:

At Greensburg an-d several points in the vicinity the interesting phenomena of the superposition of the newer upon the older drift is well shown. The best exhibit is in the southeastern part of the city, where the superficial deposits consist of about 7 feet of gray stony clay of fresh aspect, having suffered but a limited amount of superficial oxidation, and containing pebbles with polished and scratched surfaces, unleached and unweathered. This stratum is sharply terminated below and lies upon drift contrasted with it in high oxidation colors and the weathered character of the constituents. Examining more closely, the upper 2 or 3 feet of this lower stratum is found to be a loamy clay, partially stratified, and containing numerous molluscan remains. This is manifestly the superficial deposit of an old drift surface.

The writer found what seems to be a good example of the preservation of the entire white clay and its Peorian soil in an exposure in Coal Creek bluff in western Johnson County several miles inside the Wisconsin border, as indicated by the following section:

Section in bluff of Coal Creek near corners of secs. 29, 30, 31, and 32, T. 12, R. 3 E.

	Feet.
Till (Wisconsin), yellow at top but shading into blue-gray at bottom	20
Soil, black (Peorian)	1
Silt or clay, pale, greenish yellow, pebbleless (post-Sangamon)	3
Till (Illinoian), weathered and leached brown. Exposed	5
	29

The strongest evidence of an interval between the deposition of the loess and of the Wisconsin drift is perhaps found in a comparison of the amounts by which the two have been eroded. Although the erosion of the loess and associated silts is not strikingly greater than that of the outer portion of the Wisconsin drift, the difference is perceptible and indicates an interval greater than that between successive morainic systems of the Wisconsin drift. The time, however, between the loess deposition and the culmination of the Wisconsin glaciation, as marked by erosion and the forming of soil, seems to have been briefer than that between the Illinoian glaciation and the loess deposition.

[1]Third Ann. Rept. U. S. Geol. Survey, 1883, p. 333.

SAND DEPOSITS ON THE LOESS.

The sand deposits which appear on the surface of the loess in southern Indiana are found mainly along the east sides of streams and have apparently been carried to their present position by wind. They commonly occur as short winding ridges scattered over a belt from 1 or 2 up to several miles in width on the borders of the main valleys. They are very conspicuous east of the Wabash Valley in northern and also in southern Vigo County and are a notable feature south from there through Sullivan, Knox, Gibson, and Posey counties. Sand deposits are conspicuous along the east side of White River in Gibson and Pike counties but are more sparingly distributed east of the south-flowing portion of the river in Daviess and Greene counties and are rather scarce farther north. Notable deposits lie east of the great bend of Eel River in southern Clay County. In southeastern Indiana the only notable accumulations are on the east side of East White River, in Jackson County.

In some of the valleys sand flats are still exposed to wind action and mild drifting is still going on. In other valleys the bottoms are coated with a mucky clay and no sand is within reach of the wind. This muck is a marked feature in the great bend of Eel River and occurs to some extent along White River below the mouth of Eel River. The change from sandy to mucky bottoms may find its explanation in a change from glacial to modern conditions. At the culmination of the latest stage of glaciation Eel River received drainage from the ice sheet and no doubt carried sandy material down its valley. But later this connection was cut off; vegetation and soils came in, and now the river carries only mud, with which it has built up or aggraded the valley bottoms several feet. The sand deposits, on this interpretation, consist largely of the Wisconsin outwash that the wind has carried up over the bordering loess-covered tracts.

CHAPTER IV.
THE WISCONSIN DRIFT BORDER.

By FRANK LEVERETT.

CORRELATION OF THE BORDER MORAINES.

The Shelbyville or border morainic system of the Wisconsin drift of the Lake Michigan lobe in Illinois has been described in Monograph XXXVIII as far east as Greencastle, Ind. The Hartwell and Cuba, the outermost moraines of the Wisconsin drift of the Miami and Scioto lobes, respectively, in southwestern Ohio, have been discussed in Monograph XLI as far west as Connersville, Ind. There remains only an interval of about 100 miles, between Greencastle and Connersville, to be taken up in the present report.

Part of this distance, extending from Connersville west to East White River, is occupied by the moraine of the East White lobe, and the remainder is filled in by a less marked belt which connects near Greencastle with the Shelbyville morainic system. It was noted in the earlier volumes that some uncertainty was felt as to the correlation or equivalence of the outer moraines of Wisconsin drift in the Scioto and Miami lobes of Ohio, with the outer or Shelbyville morainic system of the Illinois lobe, for the reason that throughout much of the interval between Greencastle and Connersville the border of the Wisconsin drift is not marked by a definite ridge. The local names, Hartwell and Cuba, were therefore applied to the outer moraines of the Miami and Scioto lobes, respectively, though there is a strong probability that they are of the same age as the Shelbyville morainic system of the Illinois lobe.

COURSE AND DISTRIBUTION.

From Connersville, Ind., which stands in a reentrant angle between the Miami lobe and the East White lobe, the border of the Wisconsin drift leads southwestward to East White River at Elizabethtown, a few miles below Columbus, Ind. In the East White Valley the lobation is slight compared with that of the Miami and Scioto lobes, for on the west it protrudes only 10 to 12 miles. The border follows somewhat closely the east side of East White River in a course slightly west of north, to Taylorsville, 8 miles above Columbus, where it turns westward and crosses the north edge of Bartholomew County and the south edge of Johnson County into southeastern Morgan County. Thence it bears north of west across Morgan and Putnam counties to the vicinity of Greencastle, beyond which it runs westward to the Wabash Valley in Parke County, and then south and west across northwestern Vigo County into Illinois.

TOPOGRAPHY.

CONTRAST WITH ADJACENT COUNTRY.

MORAINE OF THE EAST WHITE LOBE.

In southwestern Fayette County, where the edge of the moraine of the East White lobe connects with the Hartwell moraine of the Miami lobe, its relief is only 10 to 20 feet above the silt-covered outer border tract. In northeastern Decatur County, however, for a mile or two in the vicinity of Kingston, it rises 30 feet or more above the outer plain. From Kingston southwestward to Elizabethtown, on upland tracts, a sharp rise of 10 to 20 feet from the outer border district is common. This relief, though slight, makes the border readily discernible.

The margin of the Wisconsin drift is easily traced through Decatur and Jennings counties by the soil as well as by the topography. The drift area is termed by the residents “black land,” whereas the silt-covered outer border district is termed “white clay,” “crawfish land,” or “slash land.” For more than 40 miles in Fayette, Decatur, and Jennings counties the border is so sharp and distinct that it can be located within a few yards. This abrupt change was early pointed out by Elrod, who recognized in a measure its relation to or dependence on glacial events.[1] The line of separation is very regular, passing without deviation over hills and valleys, showing but a rough adaptation to the contours, and giving positive evidence of glacial as opposed to glacio-natant drift deposition.

MORAINAL TRACT WEST OF EAST WHITE RIVER.

West of the East White Valley the Wisconsin border is less striking topographically. Instead of a ridge with continuous relief it presents only low swells and short ridges, few of which are more than 10 feet in height, and in many places they are scattered and inconspicuous. The contrast in soil is also less striking as a rule than it is east of the East White River, for the margin of the Wisconsin drift sheet is so thin and in places has so much silt or white clay incorporated with it that such occurrences can be identified only by close examination. In places the presence of pebbles alone serves to distinguish it from the white clay or surface silt of the outer border district. The admixture of silt, however, is conspicuous for only a mile or two back from the Wisconsin border, the till farther back being of a normal fresh type. And even in places where a large amount of the white clay has been incorporated with the Wisconsin till sufficient calcareous material is present to produce a richer soil than that of the white clay district. In addition to the contrast in soil the Wisconsin drift border is marked by surface bowlders of all sizes up to several feet in diameter. Outside the Wisconsin border the white clay has buried the bowlders of the Illinoian till sheet to a depth of several feet.

The course of East White River from Taylorsville to Columbus, a distance of 8 miles, was determined apparently by the Wisconsin ice invasion, for the stream

is now flowing in a narrow valley just outside the Wisconsin drift border and not in the broad old valley once occupied by a preglacial and presumably by an interglacial predecessor that lies a short distance inside the border. The present stream cuts across the lower ends of tributaries of old streams, which are traceable eastward to the broad valley by sags or depressions.

ALTITUDE.

The altitude of the Wisconsin drift border within the State of Indiana has a range of more than 500 feet. In the vicinity of the reentrant angle between the Miami and East White lobes an altitude of fully 1,150 feet is found. From the high points in western Fayette County southwestward to McCoy station in Decatur County the general altitude of the border is between 1,000 and 1,100 feet. Southwestward from McCoy it descends continuously from 1,026 feet to 891 feet at Letts Corners and 645 feet at Elizabethtown. Along East White River the altitude is between 630 and 720 feet, the latter height being reached near Taylorsville. Between East White and White rivers few, if any, altitudes exceed 850 feet, though neighboring hills just outside the border rise above 900 feet. In the valley of White River the altitude is less than 650 feet. West of White River, between Brooklyn and Monrovia, the border skirts an elevated tract which in places rises to about 950 feet, but the Wisconsin drift itself is nowhere found above 850 feet. The altitude declines to about 750 feet at Mill Creek on the line of Morgan and Putnam counties. In Putnam County it fluctuates nearly 200 feet in crossing the ridges and valleys, or from 900 to 700 feet. A prominent hill south of Greencastle, though surrounded by Wisconsin drift, seems not to have been overridden, for the upper 50 feet carries a deposit of white clay, as on ridges outside the limits of the Wisconsin drift. The upper limit of the Wisconsin drift there is about 875 feet. The Wisconsin drift extends nearly 3 miles directly south of this hill and fully a mile southwest, and drops to an altitude along the border more than 100 feet below the top of the hill. In Parke County the altitude is close to 700 feet, but in northwestern Vigo, near Wabash River, it is not much above 600 feet.

[1]Elrod, Moses, Report on Decatur County: Twelfth Ann. Rept. Indiana Dept. Geology and Nat. Hist., 1882, pp. 140-145.

CHARACTER.

From Wayne County, Ind., southwestward to the valley of East White River below Columbus, a distance of 75 miles, and for a width of 6 or 8 miles, the surface of the border is gently undulating. Few of the knolls or swells are more than 15 or 20 feet in height, and they may not average more than 10 feet, but they are so numerous and occupy so large a part of the surface as to put this border in decided contrast with the flat tract on its inner or western edge as well as with the plain of older drift on its outer.

West of East White River the knolls are in few places closely aggregated and most of them are small, like those east of the river. For 2 or 3 miles in southeastern Putnam County the border is marked by a low ridge standing 20 to 25 feet above the outer border plain. A considerable part of the border from there northwest to the Wabash Valley in Parke County shows closer grouping of the knolls, many of which are 10 to 20 feet in height.

STRUCTURE OF THE DRIFT.

CONTRAST WITH OUTLYING DRIFT.

The drift of the Wisconsin border in Indiana, though feeble in morainic expression and slight in relief above the outer border district, in structure contrasts strikingly with the outlying drift. Being relatively thin, in most places measuring but 10 to 20 feet, it may be compared at numerous points with the underlying drift. Indeed, few regions afford so good an opportunity for contrasting the Illinoian and Wisconsin drift sheets.

The outlying district shows a weathered till sheet capped by a thin deposit of light-colored pebbleless silt or white clay, generally but 3 to 5 feet in depth. The same weathered till sheet in places capped by its silt is exposed beneath the Wisconsin drift in numerous ravines.

WEATHERING.

The weathering of the surface of the Wisconsin drift sheet is decidedly less than that of the upper part of the Illinoian drift buried beneath it. In the Wisconsin drift small pieces of limestone are still present at the surface, but in the Illinoian they have been dissolved or leached out by percolating waters to a depth usually of several feet. The weathered portion of the Illinoian is a darker brown than the Wisconsin, and is tinged with red, apparently by the high oxidation of the iron. This tinge is rarely found in the Wisconsin drift surface. The Illinoian till has become partly cemented by the deposition apparently of calcareous and ferruginous material through the agency of percolating waters, but the Wisconsin seldom shows cementation. In consequence of this cementation it is much more difficult to excavate the Illinoian than the Wisconsin till. Cementation of itself is not everywhere a proof of the great age of the till, but where the lower drift sheet is cemented and the upper uncemented it corroborates other evidence to that effect. Moreover, this partly cemented lower drift can be traced continuously from beneath the newer drift into the outer border district and is found to be about equally cemented in both situations. This proves that the cementing material was not derived from the overlying Wisconsin drift, and that cementation was probably largely effected before the deposition of the latter.

BURIED SOIL.

The presence of a buried soil under the Wisconsin drift is a matter of common observation, not only along the Wisconsin drift border but throughout the northern half of Indiana and in neighboring States. In Elrod's report on Decatur County[1] the following statements appear:

The black soil bed is generally present where the bowlder clay and the yellow clay form a junction. It has never been reported as occurring in or under the blue bowlder clay[2] or its equivalent, the white clay of the "flat woods." Mr. Frank Galbraith, an intelligent observer, who has dug 11 wells in the west part of Clay Township, reports the succession to be: Soil, yellow clay and gravel, black soil frequently with buried timber, and blue clay. Mr. Enos Woodruff, in sinking two wells in the north part of Jackson Township, reports the same strata. Mr. James Bannister, of Alert, has dug four wells and found the black soil in all and timber in part of them. Buried timber is generally found in sinking wells about Newburg, on Sand Creek, and in the vicinity of Clarksburg. The finding of buried timber several feet below the surface is a phenomenon so striking to the average mind that inquiry develops the fact in all neighborhoods where the yellow clay is not replaced by sand or gravel, and frequent as the finding of timber may be, it is not nearly so often noted as the more frequent occurrence of the black soil. In thickness it ranges from 2 to 8 feet, most usually about 2 feet. In physical appearance it more nearly resembles the blue bowlder clay, and where it has apparently been disturbed at some time in its history it is mixed with gravel. Its depth below the surface ranges from 15 to 36 feet.

[1]Twelfth Ann. Rept. Indiana Dept. Geology and Nat. Hist., 1882, p. 142.

[2]Probably the partly cemented blue bowlder clay of Illinoian age.

Most of the buried soil so commonly reported in wells is probably the Sangamon soil developed at the top of the Illinoian drift, for well drillers usually report pebbles either in or immediately underlying it. In all exposures along ravines in Decatur County in the vicinity of Greensburg the black soil was found at the top of the Illinoian till, and in some the white clay above it is still present. The till beneath the buried soil, wherever observed by the writer, is oxidized to a depth of several feet.

The record of a well near Letts Corners, obtained from the well digger, shows a black soil at a greater depth than the exposures along streams would lead one to look for it. The lower part of the section is also different from the customary bluff exposures. The well did not reach rock at 83 feet, though rock is struck in neighboring wells at 20 to 30 feet. It appears, therefore, to be in the line of an old valley. The lower beds may be alluvium, as suggested in the following section:

Section of Mitchell well, 3 miles west of Letts Corners.

	Feet.
Clay, yellow, pebbly (Wisconsin till)	8
Clay, blue, pebbly (Wisconsin till?)	45
Clay, greenish (perhaps alluvium)	6–8
Soil, black, with pebbles (Sangamon or perhaps alluvium)	3–4
Clay, greenish, no pebbles noted (Illinoian or perhaps alluvium)	12
Sand, thin.	
Clay, reddish	7–8
	85

BOWLDERS.

Surface bowlders are common all along the border and, as already suggested, serve to distinguish the Wisconsin from the outlying silt-covered drift, even where the former carries a considerable admixture of silt. They are scarcely so numerous at the border as they are in certain belts which traverse the inner border district (p. 84), but they are not less numerous than over most of the region covered by the Wisconsin drift. Most of them are of granite and are sub angular rather than well rounded and do not show glaciated surfaces to such a marked degree as do the rocks contained within the till. This scarcity of glaciated surfaces characterizes the surface bowlders throughout much of the Wisconsin drift area in Indiana and in neighboring States.

In secs. 8, 9, 15, and 22, Nineveh Township, there are 40-acre lots upon which 1,000 or more good-sized bowlders dot the surface; several in secs. 15 and 22 are 10 to 12 feet in diameter. The disregard of surface elevation in their distribution is interesting. The belt in secs. 8 and 9 is on ground 50 to 75 feet higher than in secs. 15 and 22, and in adjoining sections bowlders abound both on the hills and in the valleys. This is mentioned as evidence that the present surface is essentially the same as that left by the glacier, an interpretation that opposes the view of D. S. McCaslin,[1] who held that in a number of localities heavy removal of clay was revealed by the abundance of surface bowlders, and who cited sec. 16, Nineveh Township, as a conspicuous example. McCaslin made a similar incorrect interpretation of a belt of bowlders along a moraine in the northern part of the county.

[1]Thirteenth Ann. Rept. Indiana Dept. Geology and Nat. Hist., 1884, p. 124.

THICKNESS.

Average thickness.—In places the border of the Wisconsin drift is reduced to a mere sprinkling of pebbles and bowlders, commingled with the white clay and weathered portion of the Illinoian drift; but commonly it is a sheet 10 to 20 feet thick, the upper 8 or 10 feet of a fresh yellowish brown and the remainder of a yellowish gray or blue-gray. Till forms the greater part of the border of the Wisconsin drift sheet, yet nearly every farm shows sandy or gravelly spots, and many wells that are carried to the bottom of the Wisconsin drift pass through thin beds of sand.

Sections of wells[1] in the region traversed by the Wisconsin drift border in Indiana show variation in the depth of the glacial deposits but throw little light on the Wisconsin drift as a distinct sheet. Abundant data on this subject may, however, be obtained by examining the bluffs of streams or the sides of excavations. These, as already indicated, show the thickness to be ordinarily but 10 to 20 feet and the bulk of the deposit to be till.

Well data.—The records of most of the wells along the Wisconsin drift border are not sufficiently definite to fix

the line between the Wisconsin and pre-Wisconsin drift. They are, however, of value in showing the total thickness and the variable characteristics of the drift.

In the head of the reentrant between the Miami and East White River lobes, from the vicinity of Cambridge and Dublin northward, the wells penetrate thick beds of sand and gravel and only minor amounts of till. Southward from these villages the amount of till increases, and in Rush County the border district has only thin beds of sand and gravel between the till sheets. Thus Elrod[2] reports that a well at the planing mill at Glenwood in eastern Rush County penetrated 116 feet of drift, all of which except 24 feet of fine sand from 66 to 90 feet was till. Blue till was entered at 8 feet and continued to the sand, below which there was an indurated blue hardpan, probably Illinoian. At Rushville the wells penetrate 40 to 90 feet of drift, largely blue till, though in some places containing thin beds of sand and gravel.

Elrod noted the occurrence of a buried soil and peat bed in the vicinity of Milroy in Rush County at a depth of 25 to 30 feet. He gives the following average section for that locality:[3]

Average section of wells at Milroy, Ind.

	Feet.
Soil	1–2
Clay, yellow	10
Clay, blue; replaced in some wells by sand	8–10
Clay, gray, and hardpan, usually mixed with fragments of chert and pebbles	6–8
Gravel, sand, or muck, water bearing; two wells yielded fair specimens of peat	3–5
	28–35

Wells in Decatur County show no records of especial note, but ravines afford numerous opportunities to compare the Wisconsin drift with the underlying older drift. Copper nuggets have been found along ravines in the vicinity of Milford. It was not definitely settled that they came from the older drift, but it was supposed that they did, as the older drift is known to contain copper in the southeastern counties of Indiana outside the limits of the Wisconsin drift. Should such nuggets be found in the Wisconsin drift of this region they might easily have been derived from the older deposit.

No well records of especial note were obtained in Shelby County except those in the channels traversing the southwestern part of the county. These show that the gravel is of moderate depth, till being struck not far below the level of the beds of the present streams. The filling of glacial gravel at Edinburg in southeastern Johnson County is shown by the wells to be about 30 to 40 feet. The total depth of drift, as shown by a gas boring, is 115 feet.

Wells in the vicinity of Morgantown obtain water at 18 to 20 feet from gravel below the Wisconsin drift, but a gas boring penetrated 175 feet of drift, largely sand and gravel.

[1]See county reports of Indiana Surveys; also Water-Supply Paper U.S. Geol. Survey No. 26, 1899.

[2]Fourteenth Ann. Rept. Indiana Dept. Geology and Nat. Hist., 1884, p. 55.

[3]Thirteenth Ann. Rept. Indiana Dept. Geology and Nat. Hist., 1883, p. 103.

At Monrovia most wells obtain water at- about 20 feet in sand underlying till of Wisconsin age. A well sunk by David Miller to a depth of 118 feet passed mainly through blue till thought to be Illinoian. West of Monrovia in the northwest part of Morgan County is a level tract in which wells 10 to 20 feet commonly penetrate a few feet of surface sand and a sheet of till before entering the water-bearing sand.

At Stilesville, in southwestern Hendricks County, the drift is 120 to 130 feet thick. The schoolhouse well and the public well enter a hard blue till, probably Illinoian drift, at about 40 feet.

Near New Maysville, in Putnam County, several wells have passed at about 20 feet through a buried soil which apparently lies between the Wisconsin and Illinoian drifts. With the soil are muck and leaves, showing that the pre-Wisconsin surface was swampy.

OUTWASH.

The Wisconsin drift border in Indiana, like that in Illinois,[1] appears to have had remarkably weak outwash. Thin deposits of fine sand occur along the valley of Little Sand Creek and of northern tributaries of Sand Creek which lead away from the Wisconsin border in southern Bartholomew and Jennings counties. These are probably a glacial outwash, though they may be in part a deposit of the streams in later times. But nothing found along the valleys of the large rivers, the East White and White, seems clearly referable to drainage at the maximum limits of the Wisconsin glaciation. Each valley carries a gravel plain, but much of the gravel has been brought from the moraines which cross the streams farther north. These gravel plains not only head well within the Wisconsin drift border, but they occupy valleys that had been cut down in the vicinity of the Wisconsin border below the level of the base of the Wisconsin drift prior to the deposition of this coarse gravelly material. Mill Creek and Walnut Creek and smaller streams that flow away from this Wisconsin drift border show little or no evidence of vigorous discharge down their valleys.

In explanation of this apparent weakness of discharge on the ice border Chamberlin[2] has suggested that at the culmination of the Wisconsin stage of glaciation arid conditions may have prevailed to such an extent as to favor evaporating rather than melting or liquefying of this marginal portion of the ice sheet, and that evaporation gave place to liquefaction as humidity increased.

INNER BORDER.

GENERAL FEATURES.

For a few miles back from the Wisconsin drift border the surface is generally plane or bears only scattered knolls. It shows, however, two undulating strips and two well-defined eskers that seem worthy of mention. These features are somewhat isolated, though one of the eskers terminates in one of the undulating belts. The

undulating belts, though probably formed along the margin of the receding ice sheet, are not attended by definite outwash plains or by other confirmative evidence, and their trend is somewhat out of harmony with neighboring bowlder belts. Possibly they were formed submarginally while the ice still covered the district outside.

Ravines which cut down through the Wisconsin drift, as well as borings which pass through it into the older drift, show it to be relatively thin everywhere near the border. Its thickness is generally less than 30 feet and is often but 10 to 20 feet or less. A buried soil underlies it at depths of 20 to 30 feet at a good many points 15 to 20 miles or more inside as well as along or near the border. The underlying older drift attains great thickness along the lines of old valleys, but on the interfluvial tracts is not much thicker than the Wisconsin drift. The above statements are supported by numerous data obtained from well records.

The greatly preponderating material of the drift of this region is a till, which is commonly compact and clayey rather than loose textured and sandy, and which is consequently only slowly pervious to water. Strips of sand and gravel which head in moraines to the north and lead down valleys that traverse this district properly belong to the moraines in which they head. The gravel and sand seems to have been deposited in large part after the ice sheet had withdrawn from this district. Some of the larger and steeper knolls contain gravel deposits and the eskers are composed mainly of gravel, but except in these surface gravel is rare. Beds of sand and gravel incorporated in the till are of small extent.

[1]Mon. U. S. Geol. Survey, vol. 38, 1899, p. 208.

[2]Remarks made at the Washington meeting of the Geological Society of America, January, 1903.

ST. OMAR-HOPE UNDULATING STRIP.

A strip of undulating drift about 15 miles long and 2 miles wide leads from near St. Omar in northwestern Decatur County southwestward across southeastern Shelby County to the village of Hope in Bartholomew County. It is crossed by Flat Rock Creek in Shelby County. The portion on the north side of the creek includes sharp knolls 25 to 30 feet high. South of the creek these are rare, but the wavy surface puts the strip in contrast with the flat tracts on either side.

Just outside this strip near the village of Adams a kame or gravel knoll, which is the most prominent glacial feature in Decatur County, rises 60 feet or more above the surrounding plain. Though composed largely of gravel, it has a coating of till several feet thick. The Burney esker, discussed below, also lies just outside this undulating strip.

BURNEY ESKER.

The Burney esker northwest of Burney in western Decatur County was noted and described by Elrod[1] under the name “hogback.” It extends southward about 2 miles from sec. 5, T. 10 N., R. 8 E., into the northeast part of sec. 17. Clifty Creek crosses it in the southeast quarter of sec. 5. The esker ranges from 10 to 25 feet in height and is single, except in sec. 8, where it is double for half a mile, inclosing a swampy tract about 100 yards wide. It is not accompanied by a channel or esker trough, nor does it have a fan or delta at its southern end.

The esker consists of very coarse material, its northern portion including bowlderets and cobblestones as well as gravel, and its southern portion gravel of medium coarseness. The surface deposits are on the whole coarser than the basal ones, which include considerable sand. The pebbles, both coarse and fine, are largely limestone derived apparently from the rock formations of the region. There is a tendency to bedding in conformity with the upper surface, with a dip down the slope from the crest. Such bedding is explained, on the ice-tunnel hypothesis, by the melting of the supporting ice from beneath the upper beds at the sides of the tunnel which allows them to drop down over the lower beds.

MALTA UNDULATING STRIP.

A gently undulating tract about 15 miles in length and 1 to 3 miles in width leads from near Malta in Putnam County eastward to Reno in Hendricks County, and thence southeastward past Stilesville. Its knolls are commonly but 10 to 15 feet high and are closely clustered in but few places, there being usually but a few knolls to a square mile. This undulating strip may mark the position of the ice margin at a brief halt in its withdrawal from this region.

MALTA ESKER.

The Malta esker is a ridge about 3 miles in length, which sets in on the west bluff of Clear Creek in sec. 23, T. 15 N., R. 3 W., and runs south-southwest along the edge of the valley and across sec. 27 to Warford Fork in sec. 34, where it makes an abrupt turn to east of south and ends at the south side of the valley of Warford Fork in a cluster of gravel knolls in the edge of the Malta undulating belt, about a mile north of Malta. Clear Creek crosses it through a gap about a mile south of its beginning in sec. 23.

For about a mile at the north end the esker consists of a string of low gravelly ridges scarcely 10 feet high, with gaps of considerable width. South of Clear Creek it is more prominent and is nearly continuous to Warford Fork, with a height of 10 to 30 feet and a width of 50 to 75 yards. It does not occupy a well-defined trough or channel but has its base at the level of the bordering till plain.

[1]Twelfth Ann. Rept. Indiana Geol. Survey, for 1882, pp. 143-144.

The esker consists chiefly of gravel, but it has some till-covered slopes and seems to be made up largely of till for a short distance north of Warford Fork, though

maintaining the form presented by the gravelly portion. The drift under the esker as exposed by Clear Creek and Warford Fork is a clayey till.

ST. PAUL-HARTSVILLE BOWLDER BELT.

Bowlders are distributed in small numbers throughout the border district and are especially numerous in certain well-defined narrow belts. Of these belts one of the best defined in southeastern Shelby and the adjacent parts of Decatur and Bartholomew counties is known as the St. Paul-Hartsville bowlder belt, since it runs from one of these villages to the other and extends but little beyond either village. It is about 15 miles long and 2 or 3 miles wide and has somewhat definite limits, there being several times as many bowlders for a given area within it as are found on the bordering districts. At its northern end this bowlder belt is closely associated with the undulating till tract leading southwest from St. Paul to Hope, but within a short distance it turns southward into the plain and ends several miles away from the undulating tract. It is possible that both the bowlder belt and the undulating tract mark positions held by the ice margin, but if they do the margin must have remained stationary at St. Paul while it withdrew several miles from Hartsville to Hope. This appears somewhat unnatural and leaves the interpretation of the relation of the bowlder belt to the undulating tract and of each to the ice margin unsettled. In this bowlder belt, as well as elsewhere in the border region, the bowlders are mainly granite and are from a foot or less up to several feet in diameter.

Bowlders are very numerous in a small tract in Nineveh Township in southern Johnson County. They are especially numerous in secs. 8, 9, 15, and 16, on the brow of a sandstone hill which stands 75 to 100 feet or more above the plane tracts north and east, but they are also common on these plane tracts.

In the western part of the border district bowlders are conspicuous at only a few places. Perhaps the most conspicuous occurrence is in the vicinity of Groveland and near Marysville, in Putnam County, where they abound over an area of several square miles. They are not scarce in any part of the till plain in northeastern Putnam, western Hendricks, and southern Montgomery counties, and generally are plentiful enough to supply the needs of the residents for building in localities where limestone and sandstone-are not present.

STRIÆ NEAR BORDER.

Striæ that seem referable to the Wisconsin ice invasion have been observed in several places in Indiana inside the limits of the Wisconsin drift within a few miles of the border. They bear toward the Wisconsin border and cross older striæ at large angles. In the district between Kankakee and Wabash rivers four occurrences with westward bearing are referred to the Wisconsin, and others with southward bearing are referred to earlier movements. Striæ that bear southwestward along the Sugar Creek Valley in northern Montgomery County are referred to the latest movement and others that bear southeastward and southward are referred to earlier movements. Near Greencastle several occurrences with southwestward bearing are probably referable to the Wisconsin stage and others with southward bearing seem referable to an earlier stage of glaciation. In one place on the top of Cemetery Hill, south of Greencastle, southward-bearing striæ occur above the level reached by the Wisconsin drift. Southward-bearing striæ noted by Collett in a railway cut north of Greencastle seem likely to be the product of glaciation earlier than the Wisconsin. Striæ a few miles northwest of Greencastle in sec. 30, T. 15 N., R. 5 W., stand at the very border of the Wisconsin drift. They bear about S. 20° W., which is nearly at right angles with the trend of the part of the Wisconsin border in which they occur and is somewhat divergent from the southward-bearing striæ of the earlier invasion found in that region. Some local deflection of the earlier movement may, however, have given them this bearing. Striæ in the bluff of Clifty Creek, west of Hartsville, Bartholomew County, are directed southeastward toward the Wisconsin border and seem likely to have been formed at the Wisconsin invasion. They are light but cover a convex surface which was polished smoothly. The table below includes all recorded observations near the limits of the Wisconsin drift in Indiana, whether of the Wisconsin or earlier glaciation.

Glacial striæ in Indiana.

Locality.	Bearing.[a]	Observer.	Probable age.
Quarry 3 miles southeast of Kentland	S. 77° W	Chamberlin	Wisconsin.
In same quarry	S. 7° E	do	Illinoian.
Monon	S. 85° W	do	Wisconsin.
Do	S. 34° E	do	Illinoian.
Rensselaer	S. 8°–14° W	Purdue	Wisconsin.
Rainsville	Westerly	Chamberlin	Do.
2 miles east of Williamsport	do	do	Do.
Williamsport	S. 8°–10° W	Salisbury	Illinoian(?).
Do	S. 68° E	Leverett	Wisconsin.[b]
Near Darlington	Southwest	Thompson	Wisconsin.
Do	S. 8° E	Collett	Illinoian.
Near Darlington (3 occurrences)	S. 27° 50′ E S. 23° 50′ E S. 22° 30′ E	Coulter[a]	Illinoian(?).
Near Darlington	S. 31° E	Leverett	Do.
Near Troutman	S. 8° E	Collett	Do.
Do	S. 10° W	Beachler	Do.
Sec. 20, T. 15 N., R. 5 W	S. 20° W	Campbell	Wisconsin(?).
Sec. 27, T. 15 N., R. 6 W	S. 12° W	do	Wisconsin.
Sec. 1, T. 15 N., R. 7 W	S. 27°–39° W	do	Do.
Sec. 21, T. 16 N., R. 7 W	S. 70° 30′ W	do	Do.
Sec. 24, T. 16 N., R. 7 W	S. 28° W	do	Do.
Sec. 25, T. 16 N., R. 7 W	S. 56° W	do	Do.
Railroad cut near Maple Grove	S. 10° W	Collett	Illinoian.
Greencastle	Southward	Brown	Do.
Greencastle, southwestern part	S. 28°–48° W	Chamberlin	Wisconsin.
Do	S. 40° W	Leverett	Do.
Greencastle, Cemetery Hill	Southward	Brown	Illinoian.
West of Hartsville	S. 32°–35° E	Leverett	Wisconsin.

[a] All observations have magnetic bearing except those of Coulter, which are corrected to the true meridian. [b] From Lake Michigan lobe?

GLACIAL DRAINAGE.

Traces of drainage systems which depart somewhat from the present systems are found in the eastern part of the border district. The principal headwater branch of East White River, locally called Blue River, and Flat Rock Creek, the stream next in importance, utilize part of a complex system of valleys which cut the country they traverse into large island-like tracts. This network of channels appears to have been developed on flat plains in which preglacial drainage lines had been obliterated and new lines had to be opened upon the retreat of the ice sheet. The channels mark the rambling courses taken by streams before they had become established in the present lines.

Some of the peculiarities of drainage displayed by Flat Rock Creek were noted and discussed some years since by C. S. Beachler.[1] The branching channels and the several islands inclosed by them were noted and their

boundaries mapped approximately by Collett in his report on Shelby County.[2] They were interpreted to be the lines of discharge of streams which had their source in the retreating ice sheet. Collett called attention to the presence of gravel and sand to a depth of about 35 feet below the broad bottoms of this system of branching channels and interpreted these deposits to be due to a grading up or partial refilling of the channels by the outwash from the ice sheet.

The grading up which the valleys experienced implies a large amount of preceding erosion. The removal of this gravel filling would give the valleys a depth of 50 to 75 feet or more and a combined width of 2 to 6 miles in their course through Shelby and Bartholomew counties. Notwithstanding the fact that this wide cutting has been done not in rock but in glacial deposits its amount appears very great to have been effected in connection with the recession of the ice in the Wisconsin stage. It seems more nearly in harmony with post-Illinoian erosion.

[1]An abandoned Pleistocene river channel in eastern Indiana: Jour. Geology, vol. 2, 1894, pp. 62-65.

[2]Eleventh Ann. Rept. Indiana Dept. Geology and Nat. Hist., 1881, map opposite p. 55.

An examination of the bluffs of these valleys and of the tracts inclosed by the branching channels shows that the general level of the surface of the older or Illinoian drift is higher than the gravel filling in the valleys for at least as far up the valleys as the vicinity of Shelbyville if not as far as Newcastle. This older drift is easily recognized below Shelbyville, for its outcrops are numerous and extensive, but above Shelbyville its exposures are rare and of small extent and some uncertainty is felt as to its upper limit. In addition to its occurrence in the Mount Auburn ridge, older drift lies on the border of the East White Valley about 25 feet above the gravel filling in a plain that slopes southward at about the same rate as the valley filling. The Wisconsin drift forms only a thin coating 10 to 25 feet thick on these bluffs and on the inclosed tracts between the channels, and there seem to be no grounds for assuming that its thickness is much greater inside the valleys.

On this interpretation of pre-Wisconsin excavation some difficulty may be found in accounting for the network of valleys. There would seem, however, to have been fully as favorable conditions for the development of such a network on the withdrawal of the Illinoian as on that of a succeeding ice sheet, for the slopes or attitude of the surface appear not to have been markedly different in the two stages. The branching, as in the Flat Rock drainage, seems to have arisen through stream wanderings over a flat tract on which there were no guiding channels. As the earlier drift in this region is much thicker than the Wisconsin it may have more completely effaced the channels which preceded its deposition.

CHAPTER V. CORRELATIVES OF THE CHAMPAIGN MORAINIC SYSTEM.

By Frank Leverett.

INTERPRETATION.

The outer (or main) moraine and the second moraine of the Champaign morainic system of the Illinois lobe were traced in Monograph XXXVIII to western Montgomery County, Ind., where they connected at a sharp angle with a morainic system coming up from the southeast. The outer moraine connected about 6 miles west of Crawfordsville, near the village of Wesley, and the second moraine about 6 miles farther north, immediately north of Wayne town. At the time the earlier monograph was written the morainic system trending northwest was supposed to override and conceal the northward continuation of the Champaign system. It was referred to the later Wisconsin and the Champaign was referred to the earlier Wisconsin.

The reference of the northwest-trending morainic system to the later Wisconsin was made not because of positive evidence of overriding but rather as a consequence of the bowlder belts of Warren and Benton counties, which suggested that the Huron-Erie part of the Labrador ice field occupied the vicinity of the junction of the two lobes later than the Illinois lobe. The bowlder belt does not, however, come down to this morainic system but lies a few miles east of it and diverges still farther toward the southeast. After the publication of Monograph XXXVIII the writer revisited the locality and studied quite widely in Montgomery and neighboring counties, aiming to gather all the available evidence on the relation of these moraines to each other and to the moraines and bowlder belts farther north and east. Outwash and drainage features that would throw light on the history were diligently sought, but were found singularly lacking even in the reentrant between the Illinois lobe and the lobe to the east as well as along the west side of the combined belt north of the junction of the moraines. The moraines become merged at their junction into a single belt without definite evidence of difference in the date of deposition, and without outwash from one lobe into the territory of the other. Mention should perhaps be made of a peculiarity of the headwater branches of Coal Creek that lead westward from the combined morainic system just north of the point of union. These branches flow in broad shallow sags nearly half a mile wide and only 15 to 20 feet deep, which were at first suspected to represent erosion by glacial drainage leading westward from the moraine and thus to support the theory of later occupancy by the eastern ice lobe. But further examination showed that the sags lack well-defined banks or bluffs and may have been developed by subglacial drainage. As the matter now stands nothing definite can be cited to prove that the two morainic systems are of different ages. It seems best, therefore,

to adopt the simpler alternative and to consider them as probable correlatives.

A chain of undulating belts leading from the junction of the two moraines in western Indiana to the reentrant between the East White and Miami lobes in eastern Indiana may together form a correlative of the Champaign morainic system of the Illinois lobe, though gaps of considerable width in which nothing of morainic aspect was discovered intervene between some of the links. Each of the undulating strips represents the first stand made by the ice after it retreated from the Wisconsin drift border.

COURSE AND DISTRIBUTION.

The course of the outer moraine of the Champaign system having been outlined in Monograph XXXVIII up to the point of junction with the supposed correlative west of Crawfordsville, only the moraines east of the reentrant angle need be discussed. Beginning at the northwest end of the supposed interlobate spur a few miles northwest of Crawfordsville, the moraine runs southward with a width of 3 or 4 miles to the place of junction west of Crawfordsville, passing through Wingate and just east of Waynetown. Beyond the junction it goes southeastward, crossing Sugar Creek at the bend west of Crawfordsville and continuing to Ladoga, keeping south of the Chicago, Indianapolis & Louisville Railway and maintaining a width of about 2 miles.

Near Ladoga it loses its topographic expression, there being a plain to the south and east for 6 to 8 miles, or as far as Walnut Fork of Eel River in northwestern Hendricks County. East of Walnut Fork, near North Salem, an undulating belt which is probably its continuation sets in and leads southeastward to Clayton, a distance of about 15 miles, exhibiting in places a parallel series of ridges of considerable strength spread over a width of 3 or 4 miles. From the southeastern end of this undulating belt a bowldery strip 1 to 2 miles wide leads eastward nearly at right angles to the belt. Whether this marks the trend of the ice border or was developed along the line of recession of the ice is not at present known. The position, however, seems a doubtful one for the ice border.

From Clayton a plain extends southeastward to the White River valley in northwestern Johnson County, a distance of 18 or 20 miles, where another undulating belt, beginning on the east bluff of White River, leads southeastward, passing north of Union village and south of Franklin, to Sugar Creek, a tributary of East White River in eastern Johnson County. As this belt represents the first moraine back from the Wisconsin border in Johnson County, its position corresponds with that of the undulating belt in Hendricks County. These two, therefore, are probable correlatives despite the gap of nearly 20 miles between their ends.

Beyond Sugar Creek another gap intervenes, followed in southern Shelby County by a supposed continuation of the system in a bowldery strip which sets in near Marietta on the east bluff of East White River and extends with slight interruptions, caused by gravel plains and drainage lines, across the southeastern part of the county to Cynthiana, on the east border directly east of Shelbyville, and thence bears northeastward to Rushville. From Rushville a definite ridge runs northward to Newcastle along Flatrock Creek valley, keeping west of the stream except for a few knolls in southern Henry County that are on the east side. The ridge loses its expression near Newcastle within 5 or 6 miles of the head of the reentrant between the East White and Miami lobes.

The moraine and bowlder belt east of East White River from Newcastle to Marietta holds a close parallelism to the Wisconsin border 15 to 20 miles inside that border. In Johnson County it is 8 to 12 miles back of the Wisconsin border, and in Hendricks and Montgomery counties it is 20 to 25 miles back of it

TOPOGRAPHY.

The northwest part of the supposed interlobate spur in northwestern Montgomery County, Ind., contains low knolls and ridges 20 feet or less in height interspersed with basins and flat tracts. In many places the knolls are clustered, giving the surface a very hummocky aspect. A slight tendency to ridging in the line of the moraine was noted. Southward from Elmdale the knolls and ridges are distributed along two lines between which is a tract about a mile wide with only a few knolls. Some ridges and knolls on the eastern line reach 25 to 30 feet, and a single knoll southeast of Elmdale rises to 50 or 60 feet; the great majority along both lines are, however, 20 feet or less in height.

Southwest of Crawfordsville, between Sugar Creek and Offield Creek, are narrow ridges 20 to 25 feet high, the more prominent of which trend nearly east and west. Among these are numerous small knolls 5 to 15 feet high. About midway between Crawfordsville and Whitesville gravelly knolls extend like a spur northeastward from the inner border of the moraine across secs. 14, 11, and 12, T. 18 N., R. 4 W. The largest knoll is 30 feet in height; the others are only about 15 feet. Aside from this spur the moraine south and southeast from Crawfordsville carries only low knolls 6 to 15 feet high, and this weak expression continues nearly to Ladoga. A few sharp gravel knolls 15 to 25 feet high, both east and south of Ladoga, on the borders of the Raccoon Creek valley, form the terminus of the undulating strip.

The supposed continuation in northwestern Hendricks County has a very mild expression from North Salem southeastward for 5 or 6 miles, consisting merely of a wavy surface in which the swells rise 10 to 25 feet above the sags. Near Milledgeville the inner border has sharp knolls 15 to 25 feet or more high, but is otherwise weak. A well-defined ridge sets in about midway between North Salem and Danville and, except for a slight gap 2 miles northwest of Danville, continues to that city. Where most

prominent the ridge is not less than 50 feet in height and yet is scarcely one-fourth mile in width; through most of its length, however, it is but 20 to 25 feet high. West of this ridge another 2 miles in length ends on the south about 2½ miles west of Danville; it also has a width of only one-fourth mile and yet in places rises 50 feet above the level of the plain to the west. East of these ridges are lower ones with less continuity, some of them being slightly elongated knolls, but all conforming to the northwest-southeast trend of the moraine.

East of Hadley a series of several sharp ridges, individually 1 or 2 miles long with gaps of half a mile, fills in the space of 4 miles between Hadley and Danville. The width of the ridges is one-fourth mile or less and their height only 15 to 25 feet. This morainic belt fades out in the vicinity of the valley of East Fork of Mill Creek, except that a narrow strip of undulating land continues southward along the divide between Mill Creek and West White Lick Creek about to Clayton.

The moraine in northwestern Johnson County covers a width of 1 to 4 miles and for part of its course occupies the divide between streams flowing westward or southwestward to White River and eastward to Youngs Creek, a tributary of East White River. East of Youngs Creek the moraine is only about a mile wide. In western Johnson County a slight ridge with an outer border relief of 15 to 20 feet is present for a few miles, but aside from this the moraine consists of a series of loosely connected low swells. In the tract east of Franklin knolls are conspicuous, several rising abruptly to heights of 30 to 40 feet. North of the moraine is a till plain bearing scattered sharp knolls, and a well-defined esker having its southern terminus in the moraine (p. 93). The most prominent knoll, Donnell Mound (in sec. 8, T. 12 N., R. 4 E.), rises 90 feet above bordering low ground and is slightly elliptical, with its longer axis from northeast to southwest, or about at a right angle with the moraine. Doty Mound (sec. 16, T. 13 N., R. 3 E.) is not less than 75 feet in height and has very steep slopes.

The moraine at Rushville and the bowlder belt which constitutes its westward continuation are thought to be the continuation of the chain of moraines. In Shelby County the bowlder belt is unattended by conspicuous knolls, except at the northern end of Mount Auburn Ridge, where several sharp gravel knolls may be of Wisconsin age; but from the vicinity of Rushville northward it is combined with a well-defined moraine. It does not connect closely with the eastern end of the Johnson County undulating strip, but appears about 5 miles southeast of the latter on the opposite side of the great gravel plain of East White River. It leads down the eastern slope of the Mount Auburn Ridge from its northern end nearly to Mount Auburn, or for about 5 miles, and is traceable to the edge of a slough that forms one of the numerous channels cut in the drift of Shelby County. It reappears east of this slough at Lewis Creek station and is traceable northeastward to Cynthiana, where a few low knolls appear, beyond which it is attended by scattered knolls northeastward to Rushville.

For 6 to 7 miles north from Rushville, or about to Hamilton station, there is a morainic ridge scarcely a mile in width with undulating surface and abrupt outer border relief. Farther north this ridge spreads out to about 2 miles and is less definitely ridged; most of its knolls are but 15 to 20 feet high, but a group of them in secs. 16 and 21, T. 15 N., R, 10 E., is more prominent and includes one that rises to 70 feet.

STRUCTURE OF THE DRIFT.

COMPOSITION.

Along the chain of moraines the prevailing surface portion of the drift is bowlder clay, in which pockets of water-bearing sand and gravel are so common that many wells are obtained at depths of 12 to 20 feet. The water-bearing beds do not appear to form continuous sheets; they occur at various horizons and seem to be of small horizontal and vertical extent. Gravel knolls are scattered along the entire length of the chain of moraines and are conspicuous, though they occupy but a very small part of the surface.

Surface bowlders are very unequally distributed, being hard to find in some places and conspicuous in others. On the supposed interlobate spur and also south of Sugar Creek in western Montgomery County they are numerous, and in southeastern Montgomery and northern Hendricks counties they are rare. The two larger ridges northwest of Danville and the moraine in Johnson County are thickly strewn with them, and in the district east of East White River they form a bowlder belt. More than 95 per cent of all the bowlders are of granite.

In order to compare the classes of rock found in the till and in the gravel with the surface bowlders, samples of pebbles or small pieces of rock an inch or less in diameter were collected in a bowldery portion of the drift in Johnson County and classified with the results shown in the table below. This table, though revealing striking similarity in the rock constituents of the till and of the gravel, shows striking dissimilarity between these and the surface bowlders. Glacial deposits have not been found to contain a large percentage of granite rocks except on the surface, either in this district or in other parts of the region south of the Great Lakes.

The first set of pebbles in the table is from the bluff of White River from a kame which appears to be of pre-Wisconsin age; the second set is from Donnell Mound; and the third and fourth sets are from an esker and a till plain, all of Wisconsin age.

Percentage of different rock types in glacial deposits in central Indiana.

	Pre-Wisconsin.	Wisconsin.		
	Kame on White River.	Donnell Mound (kame).	Franklin esker.	Till plain.
Crystalline, mainly granite	19.2	24.1	21.5	17.0
Sandstone	1.3	.0	.0	.0
Shale	5.1	6.6	.0	13.4
Chert	16.66	18.1	22.17	.0
Limestone (including dolomite)	57.7	51.8	56.3	69.5
	99.96	99.9	99.97	99.9
Number of pebbles classified	78	116	158	82

THICKNESS.

Variations.—Changes in the thickness of the drift are interesting and abrupt. In central and southeastern Montgomery County rock is exposed along many of the small ravines at about 25 feet below the uplands, and it is usually struck at moderate depths from Crawfordsville northwestward. In the vicinity of Crawfordsville, in a buried channel, the drift is over 200 feet thick. In central and northern Hendricks County it is so thick that wells 60 to 80 feet in depth do not reach the rock, but in southern Hendricks County rock is exposed in shallow ravines and is reached by wells at 20 feet or less. The knolls and ridges are composed wholly of drift.

Pre-Wisconsin drift.—It is rather difficult to determine how much of the drift in Montgomery and Hendricks counties is referable to the Wisconsin invasion. It may not greatly exceed the amount comprised in the knolls and ridges. In Crawfordsville, however, a buried soil was found between drift sheets at a depth of 80 to 90 feet, as reported by Owen,[1] and similar soil was found at several other places a few miles east of Crawfordsville in Boone County at depths of 45 to 65 feet.

In Johnson County the moraine begins in the western part of the county where the drift is rather thin, but runs into thick drift in the eastern part. It is probable, however, that only a few feet of the drift below the level of the base of the knolls is referable to the Wisconsin invasion. East of East White River in Rush and Henry counties the moraine is in a region presenting great differences in the thickness of the drift, the depth to rock ranging from 30 feet to 300 feet or more. The drift pertaining to the Wisconsin invasion, however, may not exceed 30 feet in average thickness, for the preglacial valleys were largely filled at earlier stages of glaciation.

[1]Ann. Rept. Indiana Geol. Survey for 1859-60, p. 133.

Well data.—The Crawfordsville gas-well boring at the railway junction in the southeast part of the city has the following drift section, as observed and reported by C. S. Beachler. It is probable that the lower or hard bed of blue clay is of pre-Wisconsin age.

Section of drift in Crawfordsville gas boring.

	Feet.
Till, yellow	12
Till, blue, soft	60
Clay, blue, hard, mixed with gravel	64
Gravel	4
	140

About one-half mile east from Crawfordsville, in sec. 33, T. 19 N., R. 4 W., a boring for natural gas penetrated 240 feet of drift; the surface is about 790 feet above sea level or nearly the same as that at the well near Crawfordsville Junction. In the valley of Sugar Creek in the north part of Crawfordsville, about 660 feet above sea level, a gas boring penetrated 150 feet of drift. About a mile north of this gas boring rock outcrops at an altitude of 750 feet or more. The change in the altitude of the rock surface within a mile is therefore about 240 feet. The rock surface rises southeast from Crawfordsville, reaching about 875 feet near New Ross.

In the north part of North Salem, Hendricks County, at an altitude about 910 feet above sea level, a well penetrated 85 feet of drift without reaching rock, and in the west part of the village one 70 feet deep stopped in drift. The gas well at Danville, which began on ground estimated to be 25 feet lower than the depot (and 871 feet above sea level), penetrated 160 feet of drift, of which the upper 43 feet contained much gravel and the remainder was mainly blue till.

The following record of a gas boring was reported by Prof. D. A. Owen, of the Franklin Baptist College:

Section of drift in Franklin gas boring.

	Feet.
Till, yellow and blue	40–45
Sand	±20
Till, blue, alternating with gravel, the till constituting about four-fifths of the material (probably pre-Wisconsin)	100
	170

A well at Mr. Burgess's residence, in Youngs Creek valley south of the courthouse at Franklin, obtains a flow from a depth of 90 feet. A flow was also obtained in the gas-well boring from about the same depth, and there is good evidence of a continuous sheet of water from one well to the other, though they are about 300 yards apart, for the water from the Burgess well became turbid soon after the gas boring began to flow.

Several wells in the north part of Franklin along a small tributary of Youngs Creek obtain flows from 40 to 45 feet, perhaps from between the Wisconsin and pre-Wisconsin drifts; and a well at the water tank of the Cleveland, Cincinnati, Chicago & St. Louis Railway in the valley of Hurricane Creek obtains a flow from about 30 feet. These shallow flowing wells probably have no connection with the Burgess well.

In the southeast part of Franklin, in the vicinity of the starch factory, several wells whose depth is only 20 to 30 feet have a common source of supply, for when an attempt was made to pump one dry the others to a distance of 75 to 100 yards from this well were lowered several feet. There seems, therefore, to be a sheet of sand or gravel below the upper till.

Owen reports the following section of a well at the Baptist College, which stands on a low gravel ridge in Franklin:

Record of well at Baptist College, Franklin, Ind.

	Feet.
Sand and gravel	16–18
Till, blue	±40
Sand, fine	2
Till, blue (probably pre-Wisconsin)	50
Gravel	4
	114

A well on the slope of Donnells Mound in sec. 8, Franklin Township, at a level about 40 feet above the base of the mound, has a depth of 50 feet. It passed through no till, but penetrated gravel to 35 or 40 feet and then entered sand.

Wells in Shelby County, in the vicinity of the bowlder belt, in places reach rock at 50 feet or less. The drift is largely a blue till. Some wells pass at about 30 feet from a soft into a hard till, which is thought to mark the top of the pre-Wisconsin drift. In central and western Rush County most wells reach rock at 50 to 75 feet, though

one near Manilla, as reported by Collett,[1] penetrated 93 feet of drift, as follows:

Section of Arbuckle & Mills boring west of Manilla, Ind.

	Feet.
Soil and clay	5
Quicksand	3
Clay, blue	5
Clay and gravel	3
Bowlder clay	17
Sand and gravel	3
Bowlder clay, blue	57
	93

At Rushville the drift may exceed 100 feet in depth on the moraine north of the city, for rock is struck at 40 to 90 feet on the plain east of the moraine. The drift on this plain and apparently also on the moraine is mainly till.

At Hamilton station a gas well penetrated 92 feet of sand and then 55 feet of hard blue till before striking rock.

OUTER BORDER.

The only gravelly outwash noted along the entire chain of moraines is found in the northern part of Rush County in the vicinity of Raleigh. The gravel is spread out over a width of about 2 miles for a length of 5 or 6 miles along the eastern base of the moraine. Several flowing wells about a mile northeast of Raleigh show that the gravel is shallow, for they are mainly through till and obtain water from the sand bed beneath the till at depths ranging from 65 to about 100 feet. A well in Raleigh 80 feet deep has ahead within afoot or two of the surface.

INNER BORDER.

TILL PLAIN.

For some miles back from the undulating strips there is a till plain with scattered knolls, few of which exceed 10 feet in height. This plain rises toward the northeast in Montgomery and Boone counties and within a short distance reaches an elevation considerably higher than that of the moraine. In Hendricks County it descends eastward from the moraine. In Johnson County it rises very gradually northward from the moraine, and in the district east of East White River it generally descends from the moraine toward the river across the inner border district. These slopes are not controlled entirely by the altitude of the underlying rock, for the ascent in Johnson, Boone, and Montgomery counties is due to a thickening of the drift.

[1]Eleventh Ann. Rept. Dept. Geology and Nat. Hist. Indiana, 1881, pp. 64-65.

In Johnson County this plain is traversed by shallow northeast-southwest depressions, in which there are chains of elliptical knolls, and in one place an esker. These sags are now occupied by small streams, High Bridge, Indian, and Hurricane creeks. Aside from these the plain carries mounds such as Bonnell and Doty mounds, already described, which are conspicuous because of their unusual height.

The drift seems to be largely a clayey til, though pockets and thin beds of gravel and sand in it furnish supplies for wells at shallow depths.

In portions of the plain bowlders are conspicuous. One belt already noted leads from a point near Plainfield in Hendricks County almost to the White River valley at Indianapolis. A very bowldery strip one-fourth mile wide and about 2 miles long lies in the southwest part of T. 13 N., R. 4 W., in Johnson County. Another belt leads southwestward from Arlington in northern Rush County along the northwest side of Little Blue River. Its course is nearly parallel to the moraine and bowlder belt, leading past Rushville, and it may indicate a brief halt of the ice margin in its withdrawal from this region.

FRANKLIN ESKER.

The Franklin esker heads in the southwest part of Franklin and leads southwestward about 3 miles to the inner border of the moraine. At its southwest end it expands into a fan-shaped plain or delta covering about one-fourth of a square mile, around which lies a swampy depression 100 yards or more in width that separates it from the moraine. The esker itself has its head in a swampy tract which extends 2 or 3 miles farther north than the esker and which seems to have been formed by subglacial drainage in connection with it. A few gravel knolls and low ridges 4 to 6 feet high in this trough are apparently referable to the stream which formed the esker.

The esker is opened extensively at its north end, where it consists of fine gravel with considerable sand intermixed. The beds are horizontal with only a slight oblique bedding. The character of the pebbles is shown in the table (p. 90).

The remarkable feature of this esker is its breadth, which in places exceeds one-eighth mile, though its height is only 15 or 20 feet above border tracts. It may, however, have been formed in a very broad tunnel in or beneath the ice sheet.

CHAPTER VI. CORRELATIVES OF THE BLOOMINGTON MORAINIC SYSTEM.

By FRANK LEVERETT.

INTERPRETATION.

The system of moraines to which the name Bloomington is applied is one of the largest developed by the Illinois lobe. It receives its name from the city of Bloomington, Ill., which stands on a prominent portion of the outermost ridge of the system. Where best developed, in eastern Illinois and western Indiana, it consists of four bulky ridges, but west of Illinois River these are merged into a bulky outer ridge and a small inner ridge. This system of moraines has been discussed in Monograph XXXVIII throughout the length of the portion developed by the Illinois lobe. It remains to consider the equivalent of this system produced in Indiana by the Huron-Erie portion of the Labrador ice field.

A massive accumulation of drift running across central Indiana from west to east was brought to notice and briefly discussed by Maurice Thompson as a "Terminal moraine in central Indiana."[1] Thompson recognized the complexity of this belt, for after outlining its course he remarked:

> I have for mere convenience called the morainic mass thus roughly outlined a terminal moraine; but I regard it a cluster or tangle of a number of inseparable moraines, caused chiefly by the separating of the great glacier into lobes and by successive advances and retreats of the ice mass.

COURSE AND DISTRIBUTION.

From the eastern end of the ridges of the Bloomington system, at the reentrant angle in Benton and Warren counties, Ind., the belt of thick drift leads southeastward across Tippecanoe and northern Montgomery, Clinton, and Boone counties into the edge of Tipton County. It there swings southward and passes through southwestern Tipton and western Hamilton and Marion counties, past the city of Indianapolis, its outer part extending into northern Johnson County. From Marion County it runs eastward across Hancock, southeastern Madison, western and northern Henry, southeastern Delaware, southern Randolph, and northern Wayne counties into Ohio. In Randolph and Wayne counties it connects with the "main morainic system" of the Miami lobe discussed in Monograph XLI. In the present report only the part in Indiana will be discussed.

TOPOGRAPHY.

ALTITUDE.

This great drift belt includes the most elevated points in Indiana, which are near the east line of the State in Randolph and Wayne counties and reach 1,250 to 1,285 feet. The lowest parts are on the border of White River near Indianapolis, where the altitude is about 725 feet, and on the border of the Wabash below Lafayette, where it falls slightly below 700 feet. The descent of 500 feet, which the moraine makes from near the Indiana-Ohio line to the White River valley near Indianapolis, is very gradual, the distance being about 70 miles. Between the White and Wabash valleys there is a rise of about 250 feet, or to nearly 1,000 feet. At the reentrant angle west of the Wabash the altitude reaches 850 to 875 feet at the highest points on the ridges near Fowler, but on the plains between the ridges it is scarcely 800 feet.

[1] Fifteenth Ann. Rept. Indiana Dept. Geology and Nat. Hist.. 1886, pp. 57-60.

The underlying rock surface shows nearly as much range as the drift surface, being over 1,000 feet near the Indiana-Ohio line, 570 feet in the vicinity of Indianapolis, 750 feet in western Hamilton County, 380 to 400 feet in the Wabash Valley near Lafayette, and from 650 to 760 feet in the vicinity of Fowler.

The altitudes of the drift surface and the rock surface on the inner plain, the drift belt, and the outer plain along several north-south lines are given in the table below. The line through Lynn shows a markedly higher rock surface at the crest of the belt than is found on the tracts lying to the north and south. West of White River the rock surface is much higher outside of than beneath the great drift belt, the drift being banked against the northeast face of a rock escarpment in Hendricks and Montgomery counties. On the line passing through Lafayette a great valley is crossed which leads westward from that city. The line running south from Fowler crosses the same buried valley near the Benton-Warren county line.

Altitude of drift surface and rock surface in cross sections.

Location.	Inner plain.		Crest of the belt.		Outer plain.	
	Drift surface.	Rock surface.	Drift surface.	Rock surface.	Drift surface.	Rock surface.
	Feet.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*
State line (Ohio and Indiana)	1,090	908–1,028	1,168	?	1,125	955
Meridian of Lynn	1,080	890–1,000	1,162	1,050	1,100	820–950
Meridian of Losantville	1,100	893	1,128	900	1,075	904
Meridian of Newcastle	950	885–950	1,090	855	1,035	550–830
Meridian of Kennard	910	825	1,041	820	980	732
Meridian of Greenfield	850	760–835	915	700	855	700
Meridian of Cumberland	770	640–715	880	600	775	560
Tipton to New Ross	872	720	988	737	888	868
Franklin to New Ross	850	575	900	580	888	868
Meridian of Lafayette	675	380–655	830	?	785	475–725
Meridian of Fowler	820	660–760	[a] 770–870	310–660	675	650
State line (Indiana and Illinois)	700	660	[a] 730–780	580–610	650	470–550

[a] The crests of the several ridges differ in altitude.

CHARACTER AND BELIEF.

The moraines of the Bloomington system are conspicuous in the vicinity of the reentrant angles where they connect with those of the Illinois lobe in western Indiana and with those of the Miami lobe in eastern Indiana, but are so weak in much of the intervening course that it is difficult to trace them individually across the State. In some places, where ridges and knolls die out, bowlder belts mark the continuation of the ice border, and in some places even these are lacking.

Warren, Fountain, and Tippecanoe counties.—The portion of the belt in the vicinity of the Wabash Valley in eastern Warren, northeastern Fountain, and

southwestern Tippecanoe counties comprises about all of it that is prominent east of the reentrant angle in western Indiana. North of the Wabash, in eastern Warren County, two strong moraines, each about 2 miles wide, separated by a nearly plane tract about a mile wide, run northwest and southeast with a billowy surface bearing a close aggregation of knolls whose height ranges from 10 feet or less to about 30 feet. The inner or eastern border of the eastern of these two belts runs from Pine Village toward Independence, leaving about 50 square miles of the northeast corner of Warren County with very flat surface. South of the Wabash, in northeastern Fountain and southwestern Lafayette counties, the morainic development is very irregular. Clusters of sharp knolls covering a square mile or more, surrounded by gently undulating or nearly plane tracts, can be linked into two parallel chains leading eastward and then southeastward into Montgomery County. Some of the knolls in these clusters reach a height of 50 or 60 feet and many reach 30 feet or more. Shawnee Mound, in southwestern Tippecanoe County, rises 60 feet above the surrounding country and 80 feet above the marsh on its northwest border. About 5 miles southeast is Cemetery Hill, also 60 feet high.

In Tippecanoe County a gently undulating surface, extending entirely across the southern townships, is about 100 feet higher than the next range of townships to the north. In places the descent to this northern plain is abrupt, but as a rule it extends over a distance of 2 miles or more. The east-west trend of the north border of this elevated undulating tract probably conforms to a late position of the ice border during the development of the Bloomington morainic system, or a bowlder belt and weak moraines which are thought to be close successors of the Bloomington system parallel it a few miles to the north. During the early development of the morainic system the ice border seems to have had a northwest-southeast trend and to have passed from southwestern Lafayette County across northeastern Montgomery County.

Montgomery County.—The strong moraines of southwestern Tippecanoe County are paralleled on the inner or northeast border by a gently undulating but very bowldery tract 1 to 2 miles wide which leads from the Wabash Valley near the Fountain-Tippecanoe county line southeastward to Linden, in northern Montgomery County, and thence past Darlington to the eastern edge of the county, about 10 miles east of Crawfordsville, beyond which it is not clearly marked. This tract is commonly known as the Linden-Darlington bowlder belt and is thought to mark a position of the ice border, but not the maximum position held during the development of the Bloomington morainic system.

The moraines of southwestern Tippecanoe County do not continue with strength into Montgomery County. The outer one is traceable no farther than the Coal Creek valley in the north edge of the county. The second one, though easily traced to Sugar Creek near Crawfordsville, lacks the strength displayed nearer the Wabash Valley. Its knolls are not closely aggregated, but inclose nearly plane tracts that occupy about half the surface. Few of them exceed 25 feet and most of them are but 10 to 15 feet high. Between Sugar Creek and the Boone County line the knolls are so scattered that it is difficult to trace the border.

Boone and Clinton counties.—Boone County, though owing its high altitude to a very thick deposit of drift, does not present definite morainic ridges. By combining a series of bowldery strips, chains of gravelly knolls, and heads of peculiar troughlike valleys that may be lines of glacial drainage, a sort of rough outline for the ice border may be drawn through the southern portion of the county. The valleys referred to are along the headwaters of Eel River and seem to have been cut by large streams which headed very abruptly in these southern townships of Boone County, as if emerging from the ice sheet. Possibly they are to some extent subglacial, but in any case they are excavated so deeply that the present streams are filling instead of eroding them. The bluffs range from 20 to 50 feet in height and are in places bordered by chains of knolls that add much to the irregularity of the surface, some of them being 20 to 30 feet in height.

In the southeastern part of Boone County bowlders as well as knolls abound. Fishback and Eagle creeks run through belts of undulating drift which in places take on a morainic appearance, especially where the knolls are thickly strewn with bowlders. In contrast to these irregularities of the southern townships the central and northeastern parts of the county are remarkably smooth, there being wide areas in which there is scarcely a knoll.

Farther north, in Clinton County, an undulating surface continues that of southern Tippecanoe County and, like it, stands above a plain on the north. It is therefore probable that during the development of the Bloomington morainic system the ice receded from southern Boone northward into central Clinton County, a distance of about 25 miles, leaving only scattered knolls and short strips of bowlders in its retreat.

Hamilton County.—The undulating tract which traverses central Clinton County from west to east curves around to the south through southwestern Tipton County and runs southward through the western part of Hamilton County. In places, as in the vicinity of Sheridan east of Horton and southeastward from Westfield to White River, sharp knolls are closely aggregated and give a decidedly morainic appearance to the surface. But on the whole the surface is gently undulating or nearly plane.

Marion County.—This undulating topography continues down the west side of White River to Indianapolis and also appears on the east bluff immediately above the city. Some of the sharpest knolls in the entire length of the morainic system are found in the vicinity, the most prominent one perhaps being Crown Hill, which stands on the east bluff near the northern edge of the city, rising about 125 feet above the gravel plain on its west side.

The southeastern part of Marion County is nearly all undulating, but the sharp knolls are restricted to a narrow strip near the east bluff of White River, or rather at the eastern edge of a gravel plain 2 to 4 miles wide that leads down the valley. A single group of sharp knolls appears on the west bluff of the river just north of the south line of the county. The river from Indianapolis southward into northern Johnson County seems therefore to follow closely the outer edge of the morainic system.

Johnson County.-—Near Glen Valley, at the south edge of Marion County, there Is a ridge about a mile In length, 75 to 125 feet in height, and scarcely one-fourth mile in width. North of it about 2 miles, near Little Buck Creek, there are ridges 30 to 50 feet in height, and between Lick Creek and the city of Indianapolis there are others. In northwestern Johnson County along the south side of Pleasant Run a ridge 50 to 75 feet high and scarcely more than one-half mile in width is practically continuous for 4 miles. From its eastern end near Greenwood a less prominent but very bowldery morainic belt, composed of knolls and ridges 15 to 40 feet in height which show a tendency to an east-west trend, runs eastward for about 8 miles. A conspicuous ridge lies east of the pike south of Greenwood. A sag border or trough about 100 yards wide, standing but a few feet below the level of the bordering plain runs along the south border of this belt for several miles In the vicinity of Greenwood, separating the moraine from the outer border plain. Possibly it was developed by border drainage, but quite as probably it was occupied by the ice during the development of the moraine and is a glacial fosse, the ice limit being on its south edge.

Hancock and western Henry counties.—The ridge in northern Johnson County just discussed, is at the south border of a broad undulating tract 12 to 15 miles in width that leads from Marion County eastward across southern Hancock and northwestern Rush counties into Henry County, its northern limit being near the Cleveland, Cincinnati, Chicago & St. Louis Railway. The belt as a whole trends nearly west and east, but individual ridges have a northeast-southwest trend and these govern the course of small streams to a marked degree. The easternmost ridge or undulating belt lies along the west side of Sixmile Creek; a second belt lies west of Brandywine Creek; a third lies west of Sugar Creek below its bend. Few knolls in Hancock County exceed 20 feet and the majority fall below 10 feet in height. In southeastern Marion County there are several square miles bearing closely aggregated knolls 15 to 30 feet high, and winding ridges of irregular shape and height inclosing basins. Near Julietta, in the vicinity of the Cincinnati, Hamilton & Dayton Railway in southeastern Marion County, a few knolls rise 30 to 40 feet above the bordering districts.

In Henry County the undulating belt narrows from about 12 miles at the western edge to less than 3 miles in the vicinity of Mount Summit north of Newcastle. The knolls are somewhat scattered where the belt is broad but show definite ridging and close aggregation as it narrows. The moraine is very strong from a point near the meridian of Newcastle eastward into Ohio.

Immediately wrest of Newcastle about 4 miles is the north end of a sharp gravel ridge which forms the front of the moraine for 5 miles, terminating on the south at the village of Greensboro. It lies along the east side of Duck Creek and rises abruptly about 50 feet above the swampy plain through which the creek flows and about 20 feet above the plain on the east. In form and constitution it is strikingly like an esker, but its position with respect to the moraine is not the usual one. Instead of leading into the moraine from the inner border district it appears to have been developed along the edge of the ice sheet. Between it and the gravel plain along East White (Blue) River is a till plain of remarkable smoothness about 2 miles in width, but on its western side the topography is morainic.

Delaware and northern Henry counties.—In southeastern Delaware County the larger knolls are chiefly along depressions or lowlands occupied by the small creeks which lead northward to White River. In many places they lie in north-south chains or nearly at right angles to the trend of the moraine.

A little farther west, in southern Delaware and northern Henry counties, a complex system of winding ridges incloses basins and marshy tracts, in which the East White River gravel plain begins. The marshy tracts drain southward into a single large channel in the northern part of Henry County.

From the head of this channel to Mount Summit a system of ridges and knolls rises abruptly 75 to 100 feet above bordering swampy tracts. Its sharpest ridges lie back about 2 miles from the edge of the gravel plain, the intervening space being gently undulating and thickly strewn with bowlders.

Randolph and Wayne counties.—In southern Randolph and northern Wayne counties, Ind., the moraine covers an uneven surface of uplands and lowlands, the lowlands being occupied by the headwater branches of Whitewater River. The ice sheet apparently overhung valleys which had been cut in the drift and deposited its knolls on the slopes and bottoms. Oscillation may have resulted in an overriding of the heads of the lines of glacial drainage. The knolls of this region are closely aggregated and thickly strewn with bowlders, but very few of them reach a height exceeding 30 feet.

STRUCTURE OF THE DRIFT.

COMPOSITION.

In most of the region traversed by the Bloomington morainic system the superficial portion of the drift is a yellow till bearing a few scattered gravel knolls, but in a district comprising several square miles in southeastern Delaware and northeastern Henry counties, about the head of the East White gravel plain (Collett's glacial

river), knolls, ridges, and intervening marshy tracts alike are composed largely of gravel. Gravelly knolls and narrow strips of flat-surfaced gravel also occur along certain valleys where the bordering uplands are till. Throughout this region the percentage of gravel is generally larger in the steep knolls than it is in the low swells, the latter as a rule being composed of till. It is not rare to find hills from which all the gravel has been removed for commercial use, leaving only till. In some hills the gravel is confined to one side; in others it forms the body of the hill, the superficial portion being till; and in still others it is in pockets on the surface, the body of the hill being till. Throughout the morainic belt in Indiana the gravel is conveniently distributed for use on the roads.

CONTACT OF WISCONSIN AND PRE-WISCONSIN DRIFT.

The occurrence of buried soil found in wells of southwestern Boone County (records of which follow) is of service in dividing the drift into earlier and later sheets, the portion above the buried soil being probably of Wisconsin age.[1]

Section of Shelly well, 4 miles north of Jamestown.

	Feet.
Soil and yellow clay, mixed with sand	12
Sand, yellow	2
Gravel, hard	4
Hardpan gravel	4
Sand, white	6
Sand and clay, bluish	18
Muck or loam, black, with branches of trees and other vegetable matter	12
Clay, blue	4
Sand, gravel, etc., gray	26
	88

[1]These records are from the Fifteenth Ann. Rept. Indiana Dept. Geology and Nat. Hist., 1886, pp. 166-173.

Section of Emert well, 2½ miles north of Jamestown.

	Feet.
Soil	2
Clay, yellow, and sand	28
Quicksand	1½
Clay, blue	29
Muck, black; leaves, twigs and branches of trees	3
Sand and clay	12
Shale, siliceous, "soapstone"	160
	235½

Section of gas well 3 miles southeast of Elizaville.

	Feet.
Soil and yellow clay	18
Quicksand	3
Clay, blue	20
Sand, white (gas)	11
Clay, blue	6
Swamp muck, leaves, twigs, etc	7
Clay, blue	19
	84

Section of Vandeveer well, 6 miles south of Lebanon.

	Feet.
Soil	2
Clay, yellow	18
Clay, blue	45
Swamp muck, leaves, twigs, etc	10
Clay, blue	25
Sandstone	9
	109

There are indications that in parts of central Indiana scarcely 20 feet of drift were deposited during the Wisconsin invasion. In western Tipton and southern Clinton counties a buried soil about 20 feet below the surface seems to represent the land surface previous to the Wisconsin invasion. In southern Madison County a black mucky soil, carrying pieces of wood large enough to be called logs, underlies the till at 15 to 40 feet.

Many deep borings made in the search for natural gas disclose the great thickness of the drift and the position of the preglacial valleys. The records of some of these borings are sufficiently definite to bring out the contrast between the soft, easily penetrated Wisconsin drift and the hard, partly cemented, underlying supposed Illinoian or pre-Wisconsin drift. As no natural exposures reach the pre-Wisconsin drift information concerning it is obtainable only from these borings. The writer, however, examined a set of samples of drift taken from a gas boring at Lebanon which was of much service in interpreting records in the neighboring districts, and he has little doubt that the change from soft to hard till marks the passage from Wisconsin to pre-Wisconsin drift.

Section of drift in Lebanon, Ind., gas well.

	Feet.
Soil, black	2
Till, yellow (Wisconsin)	9
Till, blue, becoming gray toward bottom	15
Sand with water	1½
Till, ash-colored, soft and sticky (probably Wisconsin)	77
Gravel	8
Till, pale, ash-colored, hard and dry (probably Illinoian)	53
Till, dark ash or gray, with some sand interbedded (probably Illinoian, if not older)	176
	342½

The following section of a well on Washington Street in Lebanon, as reported by Gorby and Lee,[1] shows how complex the bedding in the Wisconsin drift may be. It appears not to have reached the pre-Wisconsin.

Fifteenth Ann. Rept. Indiana Dept. Geology and Nat. Hist., 1886, pp. 170.

Section of well on Washington Street, Lebanon, Ind.

	Feet.
Soil	7
Sand, yellow	1
Clay, yellow	3
Sand, bluish, and clay	1
Sand	4
Clay, blue	3
Sand and gravel	4
Clay, blue	2
Clay, gray	3
Hardpan (indurated clay)	4
Clay, blue, laminated	14
Clay, gray	3
Sand and clay	10
Clay, blue	23
Gravel, coarse	1
Clay, blue	25
	108

At Zionsville, in the southeast part of Boone County, a gas boring entered yellow till under blue till at a depth of 88 feet, and the transit may mark the passage from the Wisconsin to the Illinoian till, though its low altitude rather favors the view that it is in the midst of pre-Wisconsin drift. The well is in the valley of Eagle Creek and may start at a level as low as the base of the Wisconsin. The following is its section:

Section of drift in gas boring at Zionsville, Ind.

	Feet.
Sand and gravel, with a little clay	30
Gravel, coarse	8
Till, blue	±50
Till, yellow and blue, in alternate beds; containing pieces of wood	±60
Bowlder, large	7
Clay, yellow	10
	165

At Sheridan, in western Hamilton County, a bed of red clay near the base of the drift may prove to be a preglacial residuary clay of exceptional thickness. The driller, Mr. Holleran, of Noblesville, noted in it decomposed pieces of white rock such as appear in

residuary clay in some limestone regions. The well was largely through blue till for 150 feet, through sand and gravel for 40 feet more, and through 43 feet of red clay resting on limestone at 233 feet.

Another well, on the Maudlin farm, 3 miles west of Newcastle, shows 243 feet of reddish clay underlying about 60 feet of ordinary yellow and blue till. Rock was struck at 303 feet. All the Wisconsin drift may be included in this 60 feet of till.

THICKNESS OF THE DRIFT.

Few well records indicate or suggest the depth of the Wisconsin drift along the belt, but a number throw light either on its thickness or its structure. These are noted below in order from the Ohio-Indiana line westward.

Randolph County.-—At Lynn two gas-well borings, each beginning at an altitude about the same as the railroad crossing (1,162 feet), penetrate one 117 feet and the other 124 feet of drift. In each the upper 50 feet is till and the remainder mostly assorted material.

In the eastern part of Winchester a gas boring passed, principally through till, to 160 feet, at which depth a bowlder was struck and the boring abandoned. West of Winchester 1½ miles a gas well penetrated 333 feet of drift, some of which is till and a large part sand. Several gas wells in the vicinity of Winchester strike rock at depths of 80 to 100 feet after penetrating more till than assorted material. A water well at Fountain Park Cemetery, in Winchester, penetrated 210 feet of drift and did not reach the rock. Another at Frank Moorman's residence in the southern part of the village did not reach rock at a depth of 205 feet.

At Windsor, in western Randolph County, a gas well penetrated 107 feet of drift, mainly sand and gravel.

At Losantville, in southwestern Randolph County, a gas well passed through 240 feet of drift, mainly till but containing some sand and gravel in its upper portion.

Henry County.—At Mooreland, Henry County, a gas well penetrated 150 feet of drift, mainly till but containing beds of gravel at about 90 feet.

In a gas boring at Mount Summit 235 feet of drift was found, mainly assorted material.

At Springport a gas well near the level of the depot, on comparatively low ground, penetrated 70 feet of drift, much of which is assorted material.

At Middletown, in Fall Creek valley, a gas-well boring penetrated 160 feet of drift, which includes some till but is mainly assorted material; a strong flow of water comes from 83 feet. Another gas well on the uplands in the north part of Middletown, about 15 feet above the level of the railway station, penetrated 203 feet of drift. Like the one in the valley it has some till, but the drift is principally sand and gravel.

A gas well 1½ miles north of Mechanicsburg, Henry County, has over 200 feet of drift, largely till. A log thought by the well driller to be sycamore was struck at about 200 feet.

At Cadiz a gas well penetrated 421 feet of drift and entered shale of Ordovician age, there being no limestone of Silurian age.

At Kennard a gas well penetrated 227 feet of alternate beds of till and assorted material in nearly equal amounts.

In the vicinity of Greensboro rock is struck at 100 feet or less.

Rock is exposed in East White River 3 miles or more above and again a short distance below Knightstown. At Knightstown several gas wells penetrate from 64 to 100 feet or more of drift. They begin on a gravel plain along the river, 50 to 75 feet above the river bed, and penetrate 20 to 25 feet of gravel, below which blue till continues to the bottom of the drift. Blue till outcrops along the river bluffs below the gravel in the vicinity of Knightstown.

Hancock County.—Several gas borings have been made in the vicinity of Greenfield. The least thickness of drift reported is 150 feet, in the valley of Brandywine Creek; the greatest thickness is about 200 feet in a well which starts at 889 feet, about the same altitude as the railway station. Nearly all the wells passed through surface till about 30 feet thick, below which are alternate beds of till and assorted material. The assorted material apparently exceeds the till in quantity.

At New Palestine the thickness of the drift is 285 feet, but the character of the material was not ascertained.

At McCordsville, in northwestern Hancock County, a gas well penetrated 186 feet of drift, mainly till.

Marion County.—In northeastern Marion County, at Oakland, a gas well penetrated 231½ feet of drift, of which the following section is reported. The well is about 35 feet below the level of the depot, 810 feet.

Section of drift in Oakland gas well.

	Feet.
Till, yellow and blue	56½
Sand and gravel	50
Till, blue, with but little sand or gravel	125
	231½

Northwest of Oakland; along Fall Creek, several gas wells penetrated partly till and partly assorted material, as follows:

Altitude and thickness of drift in wells.

	Altitude.	Drift.
FALL CREEK VALLEY NEAR OAKLAND.	*Feet.*	*Feet.*
Johnson well	770	155
Kimberlin well	777	156
Rambo well	777	177
Manseur well	770	228
Wolf well	784	160
UPLANDS NEAR FALL CREEK.		
Near Lawrence	885	188
Brightwood well	804	190
Smart well	827	190
Speese well	827	141
Irvington gas well	820	130
Cumberland	838	230

Opposite these wells the drift is much thinner north of Fall Creek than it is south of the stream, not only because the drift surface is lower but because the rock surface is higher. In a well at Cumberland about 50 feet

of yellow and blue till overlies alternate beds of assorted material and till.

The Indianapolis gas companies have bored many wells in Marion County along White River above Broad Ripple, and have found thicknesses of drift ranging from 50 to 90 feet. The least thickness found is at Broad Ripple; the greatest is west of Allisonville. About a mile east of Allisonville on the uplands, at an altitude of 75 feet or more above White River, a well penetrated only 78 feet of drift.

In Indianapolis, on the gravel plain along White River, 35 to 60 feet or more of assorted material overlies a blue till. Several wells[1] ranging in depth from 67 to 88 feet show a gravel stratum 38 to 61 feet thick. Several gas borings in the city, some on the gravel plain and some on the till tract east of the gravel plain, show drift varying in thickness from 80 to 118 feet. It is thinnest on the till tract, though the altitude there is 20 feet or more greater than on the gravel plain, and is thickest in the valley of Fall Creek near North Indianapolis, on low bottom land about 20 feet below the Union Depot (688 feet above sea level), where it is 118 feet thick.

Along White River, between Broad Ripple and Indianapolis, are some fine exposures of blue till. The bluffs are in places 60 feet high and show scarcely any gravel outcrops. Though lines of deposition or lamination have been noted[2] in this blue till, it is very pebbly, and may not differ greatly in origin from tills in which no lamination is observed.

Hamilton County.—A gas well at Carmel, in Hamilton County, in a valley near the depot, penetrated 96 feet of drift. A half mile east of this well, on ground some 30 feet higher, a well passed through 62 feet of till, beneath which was sand to the bottom of the well at 135 feet.

One of the gas wells in Westfield struck rock at 196 feet, the other at 220 feet; in both the drift is mainly a blue till. A gas-yielding well in a valley about 3 miles southeast of Westfield penetrated 95 feet of drift, of which the upper 20 feet is till and the remainder sand and gravel.

Gas wells at Jolietville and Eagletown, in western Hamilton County, each passed through about 200 feet of drift, mainly till. In the Eagletown well a bed of quicksand 20 feet thick near the bottom of the drift caused much difficulty in completing the boring.

Boone County.—At a sawmill in Royalton, in the Fishback Valley, some 60 feet below the level of the upland, a well about 100 feet deep penetrated mainly blue till, the only gravel encountered being a 5-foot bed about 25 feet from the surface.

A gas well 4½ miles northeast from Lebanon penetrated 285 feet of drift. Its section is said to differ from that of the gas well in Lebanon (p. 99) in containing less of the hard and dry ash-colored clay near the bottom.

[1]Twelfth Ann. Rept. Indiana Dept. Geology and Nat. Hist., 1883, pp. 92-93.

[2]Idem, p. 93.

A boring 5 miles west of Lebanon, on Claiborn Cain's farm, found gas in the drift at 73 to 78 feet. It was continued largely through blue clay to a depth of 243 feet without reaching rock.

The following sections and data in the vicinity of Thorntown were contributed by J. A. Ball,[1] who states that a heavy deposit of dry gravely the total thickness of which is not known, lies about 1½ miles west of Thorntown. On the farm of Mr. Charles Moffit a well was dug through 4 feet of soil and 40 feet of gravel, when it was discontinued without finding water. At other places in the same locality gravel is known to be of considerable depth.

Section of Mills well, 1 mile east of Thorntown.

	Feet.
Soil and yellow clay	25
Quicksand	3
Clay, blue	80
	108

Section of Harris well, 1 mile south of Thorntown.

	Feet.
Soil and yellow clay	19
Quicksand	4
Clay, blue	103
Gravel, cemented	6
	132

Section of Woody well, 3½ miles west of Thorntown.

	Feet.
Soil and yellow clay	18
Sand, fine, white	55
Clay, blue	71
Limestone	3
	147

Section of well near Union Church, 3 miles east of Thorntown.

	Feet.
Soil and yellow clay	27
Quicksand	9
Clay, blue	75
	111

Section of Witt & Klizer's well at Thorntown mill.

[Given by J. A. Ball, who superintended the boring.]

	Feet.
Soil	2
Clay, yellow	19
Quicksand	4
Clay, blue	125
Shale, siliceous ("soapstone")	193
	343

[Re-collected by engineer at the mill.]

Soil	2
Clay, yellow	13
Gravel	3
Clay, blue	82
Cedar tree.	
Clay, blue	37
"Soapstone"	60
Limestone, gray	136
	333

Section of Dukes & Wetherald's wells, 3 miles north of Thorntown.

[The wells are on opposite sides of the road.]

	Feet.
Soil and yellow clay	18
Quicksand	12
Clay, blue	153½
Sandstone, red	3½
	187

The present writer obtained records of gas borings at Thorntown which show much less drift than that at the mill. One in the valley of Prairie Creek in the east part of the village-penetrated about 40 feet of drift, mainly sand and gravel; the other, on the uplands in the south part of the village at an altitude 35 feet or more above the well in the creek valley, penetrated about 75 feet of drift, also mainly sand and gravel. In both a limestone occurs which is wanting in the well at the mill.

Tipton County.—At Kempton, in western Tipton County, the gas borings, although all starting at an altitude of about 925 feet, show drift ranging in thickness from 243 to 306 feet, as follows: Near depot, 306 feet; 500 yards east, 257 feet; 700 yards east, 243 feet; about a mile southwest, 260 feet.

Section of drift in well 500 yards east of Kempton station.

	Feet.
Soil and yellow till	10
Sand and till in alternate layers each a few feet in thickness, the till mainly blue	165
Gravel	65
Clay, sandy, very hard	17
	257

[1]Fifteenth Ann. Rept. Indiana Dept. Geology and Nat. Hist., 1886, p. 173.

In the well 200 yards farther east the driller recognized three series of beds, each consisting of till, sand, and gravel, in the order named. The till in the lower series is harder and drier than that in the middle and upper. The drillers were unable to give the thickness of the individual beds.

Section of drift series in well at Kempton.

	Feet.
Upper series of till, sand, and gravel	75
Middle series of till, sand, and gravel	85
Lower series of till, sand, and gravel	83
	243

Section of drift in well by Kempton depot.

	Feet.
Till	100
Sand	75
Gravel, fine	75
Clay, blue, with bowlders	56
	306

The drift in the well a mile southwest of Kempton is said by the secretary of the Frankfort Gas Co. to be mainly blue till, but no accurate record was kept.

Clinton County.—At Scircleville, in Clinton County, a gas boring, altitude 930 feet, penetrated 296 feet of drift. The upper 150 feet is mainly till. Below this thin beds of sand alternate with till for about 30 feet, beneath which is 115 feet of cemented gravel.

At Mr. Lee's, 4 miles east of Frankfort, a gas well at an altitude of about 900 feet penetrated about 300 feet of drift. A boring south of Frankfort, altitude about 860 feet, did not reach the bottom of the drift at 297 feet. Several wells along Prairie Creek in Frankfort flow -from a bed of sand beneath a heavy bed of blue till, at a depth of about 80 feet. A well in the northeast part of Frankfort, altitude about 850 feet, has the following section:

Section of drift in well at Frankfort.

	Feet.
Till, yellow and blue	30
Quicksand	10–15
Clay, hard, and gravel, interbedded	25–30
Gravel and sand, with thin beds of clay	197
Clay, blue, pebbly	13
	285

Tippecanoe County.—At Dayton, in Tippecanoe County, a boring in the valley of South Wildcat Creek, the surface of which is 50 feet or more below the level of the railway station, or about 600 feet above sea level, penetrated 160 feet of drift. The rock surface stands more than 200 feet higher at Buck Creek station, in the northern part of the county, for rock is struck there about 20 feet below the level of the depot, or 653 feet above sea level.

At the courthouse in Lafayette, in the valley of Wabash River, an artesian well penetrated 170 feet of drift, the rock surface being but 380 feet above sea level. William McKay, who superintended the boring, gives the following section:

Section of artesian well at Lafayette, Ind.

	Ft.	in.
Clay	3	
Clay and gravel	9	6
Gravel and pebbles	1	6
Gravel, fine, and sand	13	
Quicksand	1	
Gravel, clay, and pebbles	2	6
Clay, dark gray	72	
Sand and gravel	4	
Clay and pebbles	1	3
Sand and gravel	7	3
Clay		6
Sand and gravel	3	
Clay and pebbles	6	6
Gravel, pebbles, and bowlders	45	
	170	

Benton County.—At Templeton, in Benton County, altitude 700 feet, W.J. Templeton made a boring many years ago to 300 feet without reaching the bottom of the drift; no flow of water was obtained.

A gas boring on Joseph Atkinsons farm, about 3 miles southwest of Oxford, penetrated 410 feet of drift to a coal-measure shale lying about 320 feet above sea level. The drift is mainly blue till but contained beds of sand and gravel about 10 feet thick.

A boring for coal made many years ago by W. J. and L. Templeton and others on the Templeton farm 6 or 7 miles southwest of Oxford, in sec. 32, T. 24 N., K. 8 W., passed entirely through the drift. W. J. Templeton gave from memory the following section:[1]

Section of well on Templeton farm.

	Feet.
Soil	2
Clay, yellow	10
Clay, blue	25
Gas; burned for weeks.	
Clay, blue	90
Gravel, cemented	25
Clay, yellow, and gravel	110
Shale, black (?)	10
Clay and sand	100
Limestone, gray	90
Shale and limestone	75
	537

The black shale may not really be a shale, for the clay and sand which underlie it appear to be drift, which may extend to the gray limestone at 372 feet. As the altitude at this boring is probably not far from 750 feet, the top of the gray limestone lies at about 380 feet.

At Talbot, about 5 miles west from the coal boring, altitude 764 feet, a well was sunk to 310 feet without reaching the bottom of the drift. J. B. McKinney, of Fowler, who made the boring, stated that the greater part of the drift is a dry sand, of yellowish color near the top but assuming a bluish color in the lower portions. The only clay bed he recollected was a few feet thick and about 60 feet from the surface.

Mr. McKinney has made several other deep well borings in Benton County which have not reached the bottom of the drift. One at Mr. Bennett's on the ridge passing west from Parish Grove in the northeast part of sec. 33, T. 25 N., R. 9. W., is 264 feet deep, including about 25 feet of till at the surface, overlying mainly a dry yellowish sand or sandy till. On the same ridge, at Lawrence Bros., sec. 4, T. 24 N., R. 9 W., the section of a well 240 feet deep is similar.

A well at the post office in Fowler, 160 feet deep, encountered no rock; it is in sandy till or dry sand from the top nearly to the bottom, where water-bearing sand was struck. A natural-gas boring one-fourth mile north of the depot and at about the same altitude (823 feet) struck rock at a depth of 158 feet, mainly water-bearing sand. West of Fowler along Mud Creek wells penetrate 50 to 75 feet of dry sand or sandy reddish till before obtaining a good supply of water. Wells drilled by Mr. McKinney about 5 miles east of Fowler reach rock at comparatively slight depths. One in the northwest part of sec. 15, T. 25 N., R. 7 W., at Wayne Johnson's, struck rock at 65 feet; the drift is entirely till, much of it yellowish. Another well in the northwest part of sec. 10 of the same township struck rock at 72 feet; the drift is till except about 5 feet of gravel at the bottom.

A well 185 feet deep, on the farm of Samuel Davis just east of Boswell, struck no rock.

In Ambia borings have been made to 100 feet, striking rock.

[1]See also Sixteenth Ann. Rept. Indiana Dept. Geology and Nat. Hist., 1887, p. 33.

BOWLDERS.

In eastern Indiana the Bloomington morainic system is in places very thickly strewn with bowlders. A well-defined belt enters from Ohio into northeastern Wayne County and for a few miles follows nearly the line of Wayne and Randolph counties; and then passes north of west into northeastern Henry and southeastern Delaware counties. It swings abruptly southward near Mount Summit at the head of the East White gravel plain and follows the moraine about to Cadiz in western Henry County, where it ceases to be well defined. The width of the strip over which the bowlders are sufficiently numerous to seriously obstruct land cultivation is only about a mile; but from this thickest part they grow gradually fewer toward the north for several miles. In western Randolph County they abound over the whole district between White River and the southeast corner of the county. They are thicker along the southern margin of the belt in Henry County near the head of Stony Creek and of East White (Blue) River than they are farther north.

In Hancock County some small districts carry bowlders as abundantly as any part of the larger belts. One of the most conspicuous areas is found in the level portion of the county between the two branches of the Cleveland, Cincinnati, Chicago & St. Louis Railway. Bowlders occur in great abundance and large size in secs. 21, 22, 27, and 28, Vernon Township, about 2 miles south of Fortville, and are numerous along the east side of Sugar Creek southeast of Eden in secs. 25, 30, and 36, Green Township. In other parts of the county and in northern Shelby County they are not conspicuous.

In northern Johnson and southern Marion counties bowlders cover the moraine and the plain north of it so thickly that farms of 160 acres ordinarily have several thousand on their surface. They are especially numerous near Rocklane, where some fields have a hundred or more to the acre. McCaslin[1] says:

> The bowlders are everywhere thickly studded in a solid matrix of clay. Near Rocklane a multitude of unusually large ones were seen, sometimes a hundred of them in an area of a few acres, many of them 10 to 15 feet in length and weighing many tons. On the farm of W. F. Kimuck, in sec. 36, Clark Township, one was measured showing the following dimensions: Length over top, 18 feet 1 inch; circumference, 41 feet 10 inches; height above ground, 5 feet. Near this monster were a number of immense proportions. It was noticeable that there was a striking similarity in the bowlders of this ridge. They were mainly a coarse gray granite, appearing as though they came from the same locality, as doubtless they did.

In southern Marion County the bowlders are more numerous on the plain immediately northeast and east of the moraine than on the sharp ridges of the moraine itself. They are very numerous between Glen Valley and Southport and also north of Southport. In Indianapolis they are less numerous than at Southport though still abundant except on the gravel plain. At Crown Hill and northward along the east side of White River they are very abundant. They are less numerous for 2 or 3 miles west of White River than they are east of it or than they are for 2 or 3 miles east of Eagle Creek in northwestern Marion County.

In Boone County bowlders are numerous in clusters and in narrow strips a mile or so in length but do not form a well-defined belt. They are not rare, however, along the probable ice margin. Taken as a whole they seem to occupy a southeast-northwest tract 5 to 10 miles wide, which connects the more concentrated belt of Marion County with that in Montgomery County. They are rather numerous over the whole northwest fourth of Boone County, but are rare over the southwest fourth. They are abundant in the central and southeastern parts, but are rare in the northeastern part of the county. Unusual numbers were observed in the following places: In the extreme southeast section of the county; in the vicinity of Holmes station; along the Lebanon and Elizabeth pike from Lebanon northeast for about 4 miles; about a mile south of Pike Crossing; about 2 miles east of Thorntown in secs. 31 and 6, Washington Township; north of Sugar Creek, in secs. 15, 16, 22, 27, and 26, Sugar Creek Township, the southeast end being just north of Thorntown; near Dover along Muskrat Creek. The Linden-Darlington belt appears a few miles east of Crawfordsville and leads northwest to the Wabash Valley.

[1] Thirteenth Ann. Rept. Indiana Dept. Geology and Nat. Hist., 1883, pp. 123-124.

Probably the best-defined belts of western Indiana, though not associated with so strong a moraine as that of eastern Indiana, represent transitory positions of the ice margin. As already indicated the bowlder belts north of Wabash River in western Indiana cross the ridges of the Bloomington system at various angles so as to show plainly that they can not represent precisely the same ice margin that the ridges represent.

INNER BORDER.

SLOPES.

In north-central Indiana a tract of about 4,000 square miles, extending from the Bloomington morainic system northeastward to the Mississinawa morainic system and northward to Wabash River, is without strong or well-defined moraines, though it has small tracts wiiere the surface is undulatory and a few places where bowlders are numerous. In general its surface is plane and its drift is much thinner than on the belt south of it. This tract shows a westward descent of 200 to 250 feet in 45 miles, dropping from 1,100 feet at the Ohio-Indiana State line to 850 to 900 feet on the meridian of Anderson. For 20 miles west from the Anderson meridian, in Madison, Hamilton, and Tipton counties, the altitude is remarkably uniform. The southern part of the tract then rises westward into the great drift belt in western Hamilton and southwestern Tipton counties, ascending 60 to 100 feet in 8 or 10 miles. Farther north the tract very gradually descends to the northwest toward the Wabash Valley, its

altitude at the border of that valley being about 700 feet. From the great drift belt in eastern Indiana northward about to White River the descent is abrupt, being 120 feet in 10 miles from Bloomingsport to Winchester, 150 feet in 9 miles from ridges near Luray to Muncie, and 140 feet in 14 miles from Warrington to Anderson.

ESKERS.

RAUB ESKER AND ESKER TROUGH.

A depression about one-half mile in width and 20 to 30 feet in depth leads from the edge of the low plain at Raub southwestward up Little Wea Creek past the Linden-Darlington bowlder belt. It narrows sharply on entering the moraine outside the bowlder belt, and is traceable across the moraine to Shawnee Creek only through narrow sags scarcely 100 yards wide winding among the knolls. Evidence to support the view that a lake had been held between the retreating ice border and this divide was not discovered. What little channeling has been done at the divide was probably accomplished by streams issuing from the ice sheet when it stood at or near the edge of the moraine. The broad depression along Little Wea Creek is occupied by an esker which terminates at the Linden-Darlington bowlder belt, and it seems to have been developed in advance of the esker, as is usual in esker troughs.

The esker heads on the low plain 1½ miles northeast of Raub, in the south part of sec. 29, T. 22 N., R. 4 W., and is developed as a small but practically continuous ridge 8 to 10 feet high and 50 to 60 yards wide as far as Raub, where it strikes the south bluff of the channel or depression above described just east of the railroad station and is deflected northwestward about 150 yards but there turns back to its southwestward course and leads up the channel. It is interrupted in places for the first mile beyond Raub, but from there on it is nearly continuous for about 2 miles to sec. 10, T. 21 N., R. 5 W., where it attains its greatest height of about 40 feet. It enters the Linden-Darlington bowlder belt in sec. 10, and has only a weak development in the form of low knolls in this and adjoining sections on the south and west. One of these knolls near the southwest end of the esker is cut by the wagon road on line of secs. 9 and 10 and shows some till with a poorly assorted sandy gravel. The esker so far as opened elsewhere appears to be composed of gravel of medium coarseness and much better assortment than in this exposure. In Indiana and neighboring States the writer has found a few other occurrences of till with the assorted material at the morainal end of an esker. No esker fan or sand plain exists at the southwest end of the esker unless it be below the bed of the channel in which the esker lies. The esker seems to be on a slight upgrade from Raub to its southwest terminus, the altitude of its base being less than 700 feet at its northeast end, very nearly 700 feet at Raub, and 725 feet or more at its southwest terminus.

SHORT ESKERS IN SOUTHERN TIPPECANOE COUNTY.

Some of the ridges in secs. 31 and 32, T. 21 N., R. 4 W., in southern Tippecanoe County, resemble short eskers, but have around them irregular knolls such as characterize moraines. The trend of the esker-like ridges is northwest and southeast, but that of the morainic knolls and ridges is variable, some running nearly at right angles to the eskers and others being nearly parallel to them. Knolls in secs. 32 and 36 stand 30 to 40 feet above the general level. The esker ridges are lower; one, which is continuous for about 1½ miles, extending from the south part of sec. 29 southwestward to Wea Creek in the eastern part of sec. 31, is 10 to 30 feet high and nowhere exceeds one-eighth mile and in most places does not exceed 75 to 100 yards in width. It does not lie in a well-defined channel or trough, though it terminates at the southwest in a boggy tract depressed a few feet below the general level of the bordering land. North of this ridge, in the northwest part of sec. 32, a smaller gravel ridge about one-fourth mile in length, 150 yards in width, and 10 to 15 feet in height, runs parallel with it only a short space away. In the south part of the SE. ¼ sec. 30 is another ridge of similar length and trend. Terminating as these ridges do at the bowlder belt in the midst of the morainic knolls, they appear to bear a close relationship to the moraine, but being composed of assorted material and trending parallel with the ice flow and not at a right angle to it, they are thought to be the product of subglacial drainage.

HAZELRIGG ESKER AND ESKER TROUGH.

Among the esker-like ridges one worthy of note lies in the south part of sec. 23 and the north part of sec. 26, T. 19 N., R. 3 W., in Montgomery County. Though scarcely a half mile in length and 100 yards in width, it rises abruptly to heights ranging from 15 to 40 feet. It is curved, with its concavity toward the northwest. It stands in the valley of a tributary of Muskrat Creek, which here occupies a portion of a shallow channel of glacial or subglacial drainage that heads farther northeast in western Boone County in the valley of Sugar Creek in sec. 23, T. 20 N., R. 2 W., about 2 miles west of Thornton. In Boone County, and also in eastern Montgomery County, knolls and low ridges of gravel occur at short intervals along this channel, which is apparently the product of a subglacial stream, for its course is toward, and its southern terminus is in, the moraine. The channel is about one-half mile in width and is still 15 to 20 feet in depth, though partly filled with peat and muck.

ANDERSON ESKER AND CHANNEL.

Course and altitude of the channel.—A remarkable abandoned channel, consisting of a marshy valley partly filled with peaty deposits and occupied in part by an esker, passes from southern Grant County (where it drains into Mississinawa River) southward to the East White gravel plain in northern Shelby County, a distance of about 60 miles. After passing over the divide between

Mississinawa River and Pipe Creek near Summitville it leads down to Pipe Creek at Alexandria, then over the divide between Pipe Creek and White River and across White River at Anderson. Continuing southward in disregard of the present system of drainage, it crosses Fall Creek east of Pendleton and Sugar Creek at Eden (in Hancock County), and finally enters the Brandywine Valley at the point where the creek turns south a few miles north of Greenfield. It may be nearer the truth to say that Brandywine Creek enters the channel, for the latter is probably older than the creek and it is much larger than the valley of the creek above the junction. The channel is followed by Brandywine Creek to the gravel plain east of Fairland. Throughout this whole distance the channel has abrupt bluffs as if it had been cut down rapidly by a stream. It is, as a rule, but one-eighth to one-fourth mile wide, but in the portion between White River and Fall Creek its width is nearly a mile. In this wide portion it contains an esker which follows it from Anderson southward for 4 miles. It is bordered throughout nearly its entire length north of the junction with Brandywine Creek by a smooth till plain, but along Brandywine Creek the topography is of a subdued swell and sag type. Its depression below the bordering uplands for most of its length is only 15 to 20 feet, but this does not represent its original depth, for it is deeply filled with peaty material which caused much trouble in the early construction of roads across it.

The range in the altitude of this channel is not great, and the divides crossed by it are of remarkably similar heights, as shown in the table below. Beyond the last divide in central Hancock County the altitude gradually decreases down the channel.

Range in altitude along abandoned channel in Grant, Madison, Hancock, and Shelby counties, Ind.

	Feet.
Summit on divide between Mississinawa River and Pipe Creek near Grant-Madison county line (canal survey, 1835)	882
Pipe Creek valley at Alexandria (Lake Erie & Western Railroad survey)	850
Summit on divide 3 miles south of Alexandria (barometric)	890
White River at Anderson, 25 to 30 feet above present bed (canal survey)	850
Summit south of Anderson (canal survey)	889
Fall Creek valley (Cleveland, Cincinnati, Chicago & St. Louis Railway survey)	845
Summit between Sugar Creek and Brandywine Creek (Cleveland, Cincinnati, Chicago & St. Louis Railway survey)	885
Near Greenfield (Pittsburgh, Cincinnati, Chicago & St. Louis Railway survey)	835

Origin.—Two hypotheses as to the origin of such a channel may be considered. By the first it is assumed that the summits noted above mark successive positions of the ice margin and that the portion of the channel between each summit and the stream south of it was occupied by a stream which flowed no farther south but turned down the intersecting valley. For example, the broad channel leading from the summit near White River, just south of Anderson, southward to Fall Creek would be the product of a later stream than the channel leading from the Fall Creek and Sugar Creek divide southward to Sugar Creek, and still later than the one from the Sugar Creek and Brandywine Creek divide to Brandywine Creek, but earlier than the channel north of White River leading from the divide south of Pipe Creek to White River. Under this hypothesis the ice may be conceived to have had either of two quite different positions relative to such portions of the channel as lie between a given divide and stream. At the time of the formation of each channel the ice may have had its margin at the southern end of the channel, in which case the channel would have been formed by a subglacial stream; or it may have had its margin at the summit, in which case the channel would have been formed or at least enlarged outside of the ice sheet by waters that were not confined by ice walls. Certain phenomena, however, seem to be incongruous with this latter conception; for instance, the Anderson esker, which occupies the channel and rises in places higher than the bluffs of the channel and yet was evidently formed in it after the channel had been excavated, seems to call for the presence of the ice sheet and the confinement of ice walls; and again, certain gravel deposits that fringe the channel and rise in places somewhat above the level of the bordering till tracts seem to call for a stream that followed approximately the course of the channel. This second conception, therefore, seems untenable at least for that part of the channel, and the conception of a subglacial origin for the channel seems more nearly in accord with the features along the valley.

The second hypothesis as to the origin of the channel starts with the assumption that the channel was formed from end to end by a single subglacial stream that started some 60 miles back from the margin of the ice and flowed to the margin, rising and falling with the rise and fall of the surface of the ground beneath the ice sheet but ever keeping straight onward because the superincumbent ice sheet prevented escape to either side. The hydrostatic pressure is assumed to have been strong enough to have carried the stream over the low summits which lay in its course. The fact that the channel is not disjointed between the sections, as assumed in the first hypothesis, and the further fact that it rises from the valleys southward to the divides, maintaining similar sharply defined bluffs up the slope, across, and down the slope of each divide, lend, much strength to this hypothesis. Possibly there was an initial opening of the channel well toward its north end, which, during brief halts like those at Fall Creek and White River, was utilized and in places expanded by streams issuing from the margin. In this manner, perhaps, may be explained the greater size of the part of the channel between White River and Fall Creek as compared with that south of Fall Creek.

Material in the channel.—Borings have been made in or near the borders of the channel at Fairmount, Summitville, Alexandria, Anderson, Huntsville, and Greenfield. Rock rises nearly to the surface at Fairmount near the line of Grant and Madison counties, being struck at 5 to 30 feet. At Summitville a boring for gas a few rods east from the channel passed through 15 feet of till and a great depth of gravel, evidently older than the channel, and struck rock at 111 feet. At Alexandria the rock is struck at slight depth in the valley of Pipe Creek and on the uplands, so there is probably but little drift beneath the abandoned channel in the vicinity of this town. At Huntsville a gas boring near the east side of the channel penetrates 20 feet of drift, mainly muck and boggy material.

The esker.—The esker in this channel extends from the White River bluffs in the north part of Anderson nearly south-southeast for about 4½ miles to the north line of Fall Creek Township in sec. 2, T. 18 N., R. 7 E. It has a height of 10 to 40 feet and a breadth of 50 to 150 yards and is nearly continuous, being broken only by small gaps and by a few places where it is very faint. In the southwest part of Anderson, near the corners of secs. 13, 14, 23, and 24, it is most prominent. It is narrow to within one-half mile of its north end, where it expands into a level-topped ridge 100 to 200 yards wide, on which the courthouse and main business portion of the city is built. It stands 30 feet or more above the channel, which here lies almost wholly on the west. It is separated on the east from the uplands by a slight sag 8 to 10 feet or less below the level-topped portion and but 50 to 75 yards in width. The esker at its north end has very nearly the same altitude as the uplands east of the sag, 880 feet above sea level; near its southern end it rises in places 20 feet or more above the bordering uplands, the channel in which it lies being depressed about 15 feet below the upland plain.

So far as opened this esker is composed mainly of fine gravel or gravelly sand. Several wells along it in Anderson have penetrated gravel to 40 or 50 feet; and one well, at the residence of Charles Henderson, to 91 feet, a level slightly below that of White River. The lower part of this gravel may, however, be older than the esker. This abandoned channel has much gravel beneath it wherever borings have penetrated it, but as the gravel extends in places outside the limits of the channel it is likely to be in part older.

The structure and thickness of the drift are exceedingly variable in the vicinity of Anderson. On the esker at Charles Henderson's residence gravel was penetrated to 91 feet without reaching rock. At the strawboard factory in the abandoned channel only 16 feet of drift was found. At the glass works southwest of Anderson in the abandoned channel a boring passed through 194 feet of drift, all sand and gravel. In Killbuck Creek valley north of White River a gas boring encountered 50 feet of gravel and sand. On the north bluff of White River near the crossing of the Pittsburgh, Cincinnati, Chicago & St. Louis and Cleveland, Cincinnati, Chicago & St. Louis railways a gas well passed through 191 feet of drift, of which a large part was till. A water well west of the crossing of the same railways in Anderson penetrated much till and did not reach the bottom of the drift at a depth of 104 feet. On the uplands west of the abandoned channel about 2½ miles southwest from the courthouse a water well penetrated 160 feet of drift, mainly till with thin beds of fine sand, without striking rock. These records indicate that the altitude of the rock surface beneath the abandoned channel changes fully 160 feet within a short distance.

A fine gravel constituting the bulk of the esker is exposed in a pit near its south end. The bedding is discordant in the lower part but is nearly horizontal in the upper. A capping of brown clayey gravel ranges from a few inches to several feet in thickness. The cobblestones, which are numerous in the fine gravel, and the smaller pebbles are nearly all of limestone and are apparently of the same kind of rock as the underlying strata, Silurian limestone. A collection of pebbles an inch or less in diameter, gathered without attempt at selection, were classified as follows:

Pebbles in esker near Anderson, Ind.

	Feet.
Limestone, blue	36
Limestone, buff	54
Quartz	4
Chert; probably from the limestone	14
Crystalline rocks; mainly granite	22
	130

These pebbles are subangular to well rounded, especially the limestones. The granites were not much rounded. No striated pebbles were observed.

RIDGES AND BOWLDER BELTS.

GENERAL RELATIONS.

Short morainic ridges and bowldery strips in the vicinity of the Wabash Valley in Tippecanoe and bordering counties may be correlatives of the inner part of the Bloomington morainic system of the Illinois lobe, for at the west they are separated but little from the ridges of that system. One weak moraine and bowlder belt passes through the city of Lafayette, and other weak moraines or undulating strips lie between it and the Linden-Darlington bowlder belt.

HIGHGAP RIDGE.

The southernmost definite ridge of this district is known to the residents as High-gap Ridge. It leads eastward from the Wabash Valley at West Point to Taylor station on the Chicago, Indianapolis & Louisville Railway, and, after an interruption of about 2 miles at the valley of Big Wea and Little Wea creeks, continues eastward to Culver, beyond which it appears to be merged with the Stony Prairie belt discussed below. West from the Wabash it becomes blended with the innermost strong moraine of the Bloomington system and takes a northwestward course to Pine village. The most prominent portion of its independent course is that between West Point and Taylor, where a stretch of sharp knolls and ridges 15 to 40 feet in height, inclosing basins holding ponds, occupies a belt about one-half mile in width. The portion east of Wea Creek has a swell and sag topography with few basins. Its north edge was cut into sharply by what appears to be a line of border drainage connected with the next later belt.

In the portion between West Point and Taylor it is very gravelly, being little else than a chain of kames, but in the remaining portion till apparently predominates over gravel and sand. The surface is in places thickly set with small stones, but bowlders or large stones are not conspicuous.

STONY PRAIRIE BOWLDER BELT.

A belt named from Stony Prairie, in western Clinton County, is not only exceptionally bowldery but carries

numerous small drift hummocks 10 or 12 feet high that put it in contrast with smooth tracts on its borders. Bowlders are present in great numbers in secs. 15, 16, 9, 10, 3, and 4, Washington Township, and in secs. 33 and 34, Madison Township, in a belt about one-half mile wide, but are not rare east of this belt for 2 miles or more.

From the south end of the Stony Prairie bowlder belt Twelvemile Prairie runs south of east to Kirklin. Its surface is not hummocky nor thickly strewn with bowlders but is sufficiently ridged to present a well-defined crest and may mark the continuation of the ice margin in that direction. It is, however, too vague to be interpreted with certainty.

From the north end of Stony Prairie a weak belt of small knolls and shallow basins leads westward to the north side of South Wildcat Creek near Mulberry, recrossing the creek south of Dayton. Between the two crossings and from the second crossing westward a shallow channel, apparently formed by ice border drainage, follows the southern edge of the undulating belt closely to the Wabash Valley about 4 miles south of Lafayette. This belt fades out in the vicinity of the Wabash Valley and is not continued west of the river, unless it is merged with a later belt that crosses the fiver in the city of Lafayette.

The general width of this weak undulating belt is scarcely a mile, and few of the knolls in it exceed 20 feet in height. Near its inner border, however, a mile west of Dayton, a sharp knoll 60 feet high and a similar knoll east of the river form conspicuous landmarks. Basins are not rare along its southern edge, and some stand in the supposed border drainage channel, suggesting that the work in the channel was completed before the ice had entirely melted away. The width of the drainage channel averages about a mile. The fact that the stream cut strongly into the north slope of the part of Highgap Ridge bordering it is thought to indicate that the ice border stood close by the ridge at the opening of this drainage, and that the channel broadened with the melting back of the ice.

FOWLER-LAFAYETTE BOWLDER BELT.

In the north part of Lafayette the bowlder belt crosses Wabash River in a course a few degrees north of west and south of east. On the west side of the Wabash it occupies the high land between the West Lafayette reservoir and the Soldiers' Home and, covering a belt 1½ to 2 miles wide, runs westward past Montmorency and just south of Otterbien to the corners of Benton and Warren counties at the west side of Tippecanoe County. Thence it continues slightly north of west past Temple ton to Oxford, where it turns northward to Fowler and connects with an extensive bowldery area.

East from Lafayette it lies mainly on the south side of Wildcat Creek to the mouth of South Fork, though it has a small extension on the north side in secs. 12 and 13, T. 23 N., R. 4 W. East of South Fork it lies on both sides of Middle Fork in the southeast part of T. 23 N., R. 3 W., its north border being within one-half mile north of Monitor and Petit post offices. There is some uncertainty as to its continuation in Clinton County, there being only scattered knolls in the direct line of continuation and no apparent grounds for continuing the ice border in an indirect course.

The width of this bowldery belt is generally between 1 and 2 miles, and it is on the whole better defined than the Stony Prairie belt. Like the latter it covers numerous small hummocks. The drift is largely till of rather clayey texture. The border drainage is not so definite as that along the Stony Prairie belt, and it is probable that the Wabash Valley and Indian Creek valley each served as lines of drainage. On Indian Creek a gravelly terrace is thought to mark such a line. On the Wabash gravel terraces are more conspicuous below Lafayette than immediately above it, and an interbedding of outwash gravel and till at the south edge of Lafayette seems to mark the passage from glacial to fluvioglacial deposits. The gravel plain standing a few feet above the broad Wea Plain along its southern edge may prove to be the outwash at the time when Stony Prairie was forming, but the connection with that belt is not clear enough for satisfactory correlation.

MINOR UNDULATING STRIPS.

Four or five miles north of the Lafayette bowlder belt and running nearly parallel with it in western Tippecanoe and eastern Benton County a tract of undulating land standing slightly higher than the plane tracts north and south of it constitutes throughout much of its length a water parting. Its eastern end is in northwestern Tippecanoe County near Octagon, whence it passes northwestward across the southwest corner of White County and into southeastern Benton County for about 2 miles and dies out in a plain. The swells along this belt from Octagon northwestward are 10 to 20 feet high, but few of them are steep, a rise of 20 feet generally requiring fully one-eighth mile of slope. There is scarcely any level land in the belt. In the vicinity of Octagon a tendency to ridging in an east-west direction was noted.

The Octagon undulating tract is bordered by a sand ridge 5 to 15 feet high and 100 to 300 yards wide, composed of fine yellow sand, which sets in about 5 miles west of Brookston in Northern White County and leads south-westward for 10 miles across the northwestern part of Tippecanoe County into southeastern Benton County. Were the ridge of gravel instead of sand it would seem best explained as an esker, bat careful search failed to bring to light any pebbly material in it. Were the bordering material sand instead of clayey till the ridge might be ascribed to the wind. But there is almost no sand on the bordering districts and little if any evidence of lake occupancy of the region after the retreat of the ice. The origin of the ridge, therefore, remains uncertain. Very few points within several miles are higher than the ridge, which stands on a prominent part of the upland 700 feet or more above sea level.

Another modulatory strip 1½ miles wide, carrying basins as well as low swells, follows Fall Creek from Middletown to Pendleton in Madison County, but does not appear to extend west of Pendleton.

Another gently undulating strip about a mile wide follows the north side of White River from Anderson westward-to the Hamilton County line, where it crosses to the south side of the valley and continues between White River and Stony Creek, apparently terminating at the bend of White River north of Noblesville. Bowlders are somewhat more numerous on it than on border plains, but few of the swells exceed 10 feet in height, and no connection was established between it and any well-defined moraine.

Along North Wildcat Creek from Burlington to Cutler and south from there to the vicinity of Sedalia in northern Clinton County there is an isolated belt of a dozen or more square miles in which knolls 20 to 40 feet high occur.

Along the east bluff of the Wabash in Carroll County a belt a mile or more in width displays a tendency to ridging parallel with the river. The most prominent ridges lie west of Rockfield in secs. 1 and 2, T. 25 N., and sec. 36, T. 26 N., R. 2 W.; they stand 20 to 30 feet above the low ground between them and slightly less above the plain to the southeast. About 3 miles northeast of Delphi, near the corners of secs. 14, 15, 22, and 23, a group of gravel knolls rise rather sharply 12 to 15 feet above interspersed basins. Together they cover less than a square mile. All around them the surface is very gently undulating.

What is perhaps the best-defined and longest undulating strip in the district consists of scattered knolls distributed over a strip 1 to 5 miles in width, leading from Muncie northwestward to Peru. Its south border in western Delaware County leads westward near the line of the Lake Erie & Western Railroad into Alexandria. After crossing a swampy channel west of Alexandria it turns northwestward and leads past Rigdon and Point Isabel into Howard County, where for a few miles it forms the divide between Wildcat Creek and the headwaters of Pipe and Deer creeks. It runs into Miami County between the north and south forks of Deer Creek past the village of Wawpecong, comes to North Deer Creek at Miami village, and thence runs north to Pipe Creek and Bunker Hill. It then follows Pipe Creek valley north-westward to the Wabash at the line of Miami and Cass counties about 5 miles west of Peru. Few places in this strip bear knolls exceeding 15 feet in height, and less than one-fourth of the surface is more undulatory than the bordering plains. Only in Miami County do bowlders abound and they are about as numerous west of the undulatory strip as they are along it.

STRUCTURE OF THE INNER BORDER.

COMPOSITION.

General features.—Till constitutes the greater part and especially the surface portion of the drift of the intermorainic tract or inner border. What little gravel there is on the uplands is in the sharp knolls or in small patches in the till plain, there being no extensive gravel plains. Along the valleys of the principal streams considerable gravel and some gravel knolls and ridges occur. There is also, as indicated above, gravel in the Anderson esker and in the abandoned channel in which the esker lies.

Wells in Boone, Clinton, and Madison counties (see p. 99) pass at depths ranging from 15 to 60 feet through a black mucky soil which may indicate the top of the deposit at the preceding ice invasion. A soil is struck in some localities at exceptional depth—for example, at 103 feet in the “Brobst” gas well in southeastern Howard County.

Of many well sections and estimates of drift thickness collected, the following have been selected:

Delaware County.—At Muncie the thickness of drift in the several gas borings ranges from nothing to 100 feet, though the altitude of the surface does not vary more than 25 feet.

At Daleville wells penetrate 8 to 15 feet of yellow till and obtain water at slight depth in sand and gravel. A gas well penetrated 12 to 15 feet of yellow till. The remainder of the drift is sand and gravel. Rock was entered at 85 feet.

Madison County.—At Markleville a gas boring penetrated 147 feet of gray till containing thin beds of sand and gravel. A piece of wood was struck at about 140 feet. The altitude of this well by gravel-road survey is 100 feet above Pendleton, or 945 feet above the sea.

In Elwood gas well No. 1 penetrated 108 feet of drift, mainly blue till. Gas well No. 2, near Duck Creek, at an altitude 10 or 12 feet lower than No. 1, penetrated 65 feet of drift, mainly till, except for about 12 feet of sand at the bottom. Gas well No. 3, one-half mile east of the village on ground as elevated as No. 1, penetrated only 40 feet of drift.

Hamilton County.—At Clarksville, P. P. Whitesall has a gas well which penetrated 16 feet of drift, and his neighbor William Coverdale has another at a similar altitude that penetrated 82 feet of drift. At Mr. Sohl’s, about a mile west of Clarksville, two wells penetrate each only 6 feet of drift.

Two miles east of Noblesville, at the “Granger wells,” the drift is 80 feet thick, of which the greater part is gravel. Near Noblesville nearly all the gas wells and water wells penetrate much gravel, the only marked exception noted being a well west of White River in which till constituted the bulk of the 98 feet of drift. Many of the wells, however, in which the greater part of the drift is sand and gravel, contain a thin bed of surface till. The thickness of

the drift varies considerably, a well two blocks north of the courthouse in Noblesville having 136 feet, another one-half mile north in White River valley at an altitude about 30 feet lower having only 33 feet, and a third 1½ miles north of the courthouse on the upper gravel terrace along the river passing through 176 feet. In this last well assorted material persisted to 40 feet or less of the bottom, at which depth a red ocherous clay overlying the limestone was entered.

At Cicero the following sections of drift in gas wells were reported by William Neal: Well No. 1 has 161 feet of drift, of which the upper 15 feet is till and the remainder more sand and gravel than till. Well No. 2, on ground 8 or 10 feet lower than No. 1, has 141 feet of drift, which includes more till than No. 1 but has a large component of sand and gravel. Well No. 3, a mile south of Cicero, at an altitude not perceptibly different from that of No. 1, has 270 feet of drift, including a bed of till about 20 feet thick at the surface; below this for 175 feet the drift is chiefly sand and gravel, with thin beds of clay; the lowest part (about 60 feet) is a red clay, apparently like that at Noblesville, in which no pebbles were noticed.

At Arcadia records of two gas wells show 146 and 130 feet of drift, nearly all till, mainly blue. Thin beds of sand and gravel were passed through.

At Atlanta, near the line of Hamilton and Tipton counties, a gas well penetrated 320 feet of drift, consisting of yellow and blue till to about 80 feet and of sand and gravel on to the bottom.

Tipton County.—In southeastern Tipton County at Mr. Hobbs's residence in sec. 36, T. 21 N., R. 5 E., a well struck rock at 73 feet. The following is the section of drift:

Section of drift in Hobbs well in southeastern Tipton County.

	Feet.
Till, yellow	15
Till, blue, putty like; few pebbles	50
Sandy material, yellow with crust of gravel	8
	73

In the level plain along the Lake Erie & Western Railroad east of Hobbs station there is a small tract of surface gravel which is used for ballast on the road. In this gravel bed many large angular blocks of limestone are embedded. Near Hobbs station are two gas wells. One in sec. 1, T. 21 N., R. 5 E., penetrates the following beds of drift:

Section of drift in gas well at Hobbs station.

	Feet.
Till, yellow and blue	38
Gravel	5
Till, blue	45
Gravel	15
	103

Other sections in this county are given below.

Section of drift in well in sec. 10, T. 21 N., R. 5 E.

	Feet.
Till, yellow	10
Gravel	20
Till, blue	80
Gravel	20
	130

Drift in wells at Tipton.

[Altitude about 870 feet.]	Feet.
Well No. 1, in north part of village	139
Well No. 2, one-half mile west of No. 1	152
Well No. 3, in east part of village	200

A gas well at Windfall, in northeastern Tipton County, penetrated 72 feet of drift, mainly blue till, but including thin beds of sand and gravel.

Howard County.—At the Barrett gas well, in southeastern Howard County, in sec. 21, T. 23 N., R. 5 E., is the following section of drift:

Section of drift in Barrett well.

	Feet.
Till, yellow	10
Gravel, loose	40
Gravel, cemented	48
	98

In the Probst well, sec. 7, T. 23 N., R. 5 E., the well driller reports striking beneath the till, at 103 feet, a bed of dirt and leaves, underlain by sand and gravel extending to limestone at 115 feet.

At Tampico two gas borings show a difference of 28 feet in the thickness of drift, the thicker being in the well on the lower ground. In each the upper portion, to a depth of 25 feet, is till and the remainder sand and gravel with thin beds of till.

At Sharpsville a gas well penetrated 70 feet of drift, mainly till.

A gas well 4 miles east of Russiaville, in southern Howard County, penetrated 165 feet of drift. A boring in Russiaville penetrated 153 feet, of which the upper 60 feet is till and the remainder largely sand and gravel.

In several wells in Kokomo and vicinity drift is absent or ranges up to 88 feet in thickness.

At Greentown, 8 miles east of Kokomo, most wells obtain water at 20 to 25 feet in gravel below till. A lower vein of water is struck at 35 to 45 feet. Gas borings show the drift to be about 85 feet in thickness.

At Fairfield a village well struck rock at 47 feet, another well one-fourth mile northeast on slightly lower ground at 72 feet, and a third one-half mile north of the village on ground about 20 feet lower than the first well at 26 feet. In all these wells the drift is mainly till. Most of the wells draw from beneath the first sheet of till at 20 or 30 feet. A well near the railway station has 47 feet of drift, of which the upper 18 or 20 feet is till and the remainder gravel. Gas borings show the drift to range from 25 up to fully 75 feet.

Grant County.—In southwestern Grant County the drift is thin and consists of a few feet of till underlain in many places by a bed of water-bearing sand or gravel. Gas borings show the following thicknesses: At Switzer, 28 feet; Swayze, 22 feet; Simms, 45 feet; Point Isabel, 22 feet; Fairmount, 5 to 35 feet.

Miami County.—At Xenia (Converse post office) dug wells end at 10 to 20 feet in gravel beneath a sheet of till. The drift ranges from 25 up to 100 feet or more in thickness. In the southeastern part of the county many wells penetrate 50 to 70 feet of till, though shallower ones are common.

At Amboy the wells penetrate about 15 feet of till, beneath which a water-bearing gravel extends to rock at 35 to 50 feet.

At Bunker Hill a sheet of till 25 to 40 feet thick is generally passed through before waterbearing sand or gravel is reached. In one gas well the drift is 68 feet, in another 84 feet; in each the lower half is largely sand and gravel. A boring east of Bunker Hill in sec. 21, T. 26 N., R. 5 E.; at an altitude 175 feet above Wabash River at Peru, penetrated 160 feet of drift, of which 54 feet is till and the lower 6 feet gravel.

Cass County.—At Galveston, Cass County, on ground 20 feet lower than the railway station, or 775 feet above the sea, a gas boring penetrated 41 feet of drift. Rock outcrops along Deer Creek west of Galveston.

At Walton the drift is about 80 feet. At Logansport drift is lacking in the valley and is very thin for some distance to the south on the uplands.

Carroll County.—At Delphi also drift is lacking in the valley and is thin on the uplands to the east and south.

At Flora there is 136 feet of drift, mainly till. Several flowing wells near the creek differ in depth, some being but 12 feet and others 40 to 45 feet deep. In the deeper two water beds occur above and below beds of blue till. There is said to be a ferruginous crust above the water beds and the water is strongly chalybeate. The probable source and head of water is from the higher ground south and southeast of Flora.

Clinton County.—Two wells near Geetingsville, on a knoll at R. G. Young's, only 50 yards apart, show a marked difference in material:

Record of Young well No. 1.

	Feet.
Sandy and gravelly clay	12
Till, bluish-yellow	33
Gravel	6
Till, bluish-yellow	14
Sand	6
	71

Record of Young well No. 2.

	Feet.
Clay, sandy and gravelly	6
Sand	25
Gravel, coarse, at bottom	2
	33

Dr. Young has a well on a level tract in the village of Geetingsville 125 feet in depth which does not reach the bottom of the drift. The section was not obtained. At J. H. Brown's residence, one-half mile west of Geetingsville, is a gas-yielding well with the following section:

Record of Brown well.

	Feet.
Till, yellow and blue	68
Sand and vegetable material with gas; sand cemented in places	16
Sand, with thin clay beds	40
Gravel	2
	126

Several Rowing wells have been obtained in a valley in sec. 19, T. 23 N., R. 13 E., at a depth of only 20 feet.

At Mr. Stevenson's, about 2 miles west of Sedalia, a well was driven through 80 feet of till. No sand was noted and no water obtained. Afterward a well was dug at the same spot, and water was obtained in a thin sand bed at 20 feet. This illustrates the fact that the reported section of a driven well is less reliable than that of a dug well or large excavation.

At the railway station in Mulberry a well was driven, mainly through blue till, to a depth of 220 feet without reaching rock.

Tippecanoe County.—From well sections given by Gorby in his report on Tippecanoe County[1] the following, which represent the deepest wells, are reproduced:

Section of Kinney well, sec. 15, T. 22 N., R. 4 W., 2½ miles east of Culver.

	Feet.
Soil	2½
Clay, yellow	8
Clay, blue	40
Hardpan	3
Water at	53½

Section of well at schoolhouse No. 6, Wea Township, 3 miles southwest of Culver.

Soil	2
Clay, yellow	8
Sand and gravel	6
Clay, blue	41
Water at	57

Section of Hicks well at Battle Ground (on terrace of Wabash River).

Soil	3
Hardpan	3
Gravel and sand	73
	79

Section of Clue well at Battle Ground.

Soil and yellow clay	4
Gravel, coarse	25
Sand	30
Clay, blue	1
	60

Section of Thomas well, 3½ miles east of Battle Ground.

Soil and clay	4
Gravel and sand	20
Hardpan	20
Sand and gravel	25
Clay, gray	2
	71

Section of Hoyleman well, 4½ miles northeast of Battle Ground, in Moot Creek valley.

Soil and clay	6
Clay, hard, blue	54
No water at	60

Section of Peffley well, 1 mile northwest of Colburn.

	Feet.
Soil and clay	4
Clay, blue	40
Gravel, dry, coarse	20
No water at	64

Section of Livingston well, 2 miles west of Battle Ground.

Soil and yellow clay	30
Sand, fine, dry	20
Clay, blue	30
Gravel, cemented	2
Gravel, loose	13
Water at	95

Section of Bryant well, 3 miles west of Battle Ground.

Soil and yellow clay	4
Clay, blue	50
Sand, dry	20
Gravel, coarse	2
No water at	76

Section of Brown well at Buck Creek station.

Soil	2
Clay, yellow	3
Clay, blue	15
Sand, fine, yellow	30
	50

Section of Cole well, 1¾ miles west of Buck Creek station.

Soil and yellow clay	6
Gravel and sand	49
Clay, blue	5
	60

Section of Stanfield well, 2 miles north of Buck Creek station.

Soil and clay	4
Fine sand	45
Gravel, coarse	12
Gravel, fine, with bowlders at bottom	4
Water at	65

[1] Fifteenth Ann. Rept. Indiana Dept. Geology and Nat. Hist., 1886, pp. 87-95

Data concerning deep wells at Dayton and Lafayette are presented in the discussion of the Bloomington morainic system. In the northwestern part of Tippecanoe County there are deeper wells than any reported by Gorby, but the writer was unable to obtain reliable records of them. One on the Van Alla estate in the east part of sec. 18, T. 24 N., R. 5 W., 126 feet deep, struck no rock, nor did one 176 feet deep on a farm 2 miles northeast of Otterbein in sec. 26, T. 24 N., R. 6 W.

BOWLDERS WITHIN THE INNER BORDER.

Bowlders are not numerous except in very small patches on the great intermorainic tract and no system in their distribution was detected by which an ice margin could be marked out. The bowlders are mainly crystalline rocks, more than half being granite and the bulk of the remainder basic eruptives. A few red jaspery conglomerates from north of Georgian Bay were noted.

In the Wabash Valley at Logansport bowlders are exceedingly numerous, numbering where thickest 1,000 or more per acre. They also abound at intervals below Logansport for several miles. These bowlders are probably a residue left where the drift has been cut away by the river.

STRIÆ IN THE INNER BORDER.

Striæ have been observed at five localities within the boundaries of the intermorainic tract. Exposures of rock

strata are few and there is little opportunity for observation.

In a few places in a quarry south of and near White River about a mile below Anderson a flinty layer upon which striæ appear caps a shale that forms the greater part of the surface rock. The striæ bear from due south to S. 10° W. (magnetic).

Striæ were observed upon ledges in the north part of Free's quarry on the north side of a small stream in the southwest part of Alexandria, where the surface rock is a thick-bedded blue limestone which dips very gently west (about 1 foot in 150 feet). The surface is planed and on it shallow grooves one-fourth inch or less in breadth bear S. 39° W. (magnetic). The striæ near Anderson are in harmony with the trend of the esker and its trough, but those at Alexandria are not.

Striæ are found at the quarries south of Kokomo, on a small tributary of Wildcat Creek and just east of the Pittsburgh, Cincinnati, Chicago & St. Louis Railway. The rock here is a thin-bedded blue limestone, and the marks appear over the whole of the uncovered surface, comprising an area of several square rods. Most of them are fine lines, only 1 to 4 inches in length, the majority of which bear S. 50° to 70° W., but a few scattered ones bear from S. 20° E. to S. 80° W. The great difference is perhaps due to a changing series of ice currents, the locality being directly in front of the great curve in the drift belt, where the north-south trend in Hamilton and Tipton counties changes to east-west trend in Clinton County. Currents of ice in Howard County might pass southward against the western limb of the White River portion of the great drift belt or southwestward against the eastern limb of the Wabash River portion.

At the Davis bridge on Eel River northeast of Logansport the rocky bed of the river displays glacial groovings which bear S. 58° W. and some of which are several yards in length. The largest are 2 inches or more in width and one-third inch in depth. At the western end some of the grooves terminate abruptly at flinty places in the rock. Tapering projections in the lee of flinty prominences evidently owe their preservation to protection against the westward-moving ice. To this feature Chamberlin has applied the name "knob and trail."[1]

Glacial grooves and striæ were observed within the city limits of Logansport on the north bank of Eel River just below the upper dam, on a rocky ledge a few feet above the level of the river, where nearly all of a magnificent series bear S. 14° E. (magnetic). All the grooves have this bearing, but some of the striæ or fine lines bear more nearly south, the most southerly being S. 5° E. A careful search was made for evidence on the surface that would be decisive concerning the direction of ice movement, for it seems not unlikely that the moraine north of the river might have been formed in part by a lobe spreading northward, but nothing satisfactory was discovered for there are no prominent flinty knobs such as occur in the exposure in Eel River. Some light scratches which cross the grooves with a bearing S. 70° W., or in about the direction of the flow of Eel River, look in places much like glacial striæ, but they may have been formed by river ice. They appear only on the prominent parts of the rock surface and are very light and but a few inches in length.

GLACIAL DRAINAGE.

OUTER BORDER.

WHITEWATER RIVER BASIN.

East and West Whitewater rivers and some of their principal tributaries in Wayne County bear gravel plains which show that they were occupied by streams that flowed southward from the margin of the ice sheet while it was forming the moraines of northern Wayne and southern Randolph counties. These gravel plains constitute the terraces of the Whitewater and may be traced to an Ohio River terrace that stands approximately 100 feet above the bed of the river at the place where it is joined by the Whitewater gravel plain. The streams at the north ends are incised but little in the gravel plains, and they therefore descend about 100 feet more than the glacial streams in reaching the Ohio. Before the Whitewater had been filled with glacial gravel its bed was much lower than at present, as is well shown by borings at and near Brookville which enter rock 100 to 120 feet below the present stream. The valleys of the Whitewater system were probably filled in large part by earlier moraines than that under discussion, but it is quite likely that they received important additions of gravel and sand from it throughout their whole length.

[1]Seventh Ann. Rept. U. S. Geol. Survey, 1888, p. 246.

EAST WHITE RIVER BASIN.

Westward a few miles from the Whitewater system is the head of the great gravel plain which is followed by East White (Blue) River. Its northern end is among the morainic ridges of southeastern Delaware County, whence a complex network of channels leads out to form the gravel plain. Prairie Creek has a channel one-fourth mile or less wide with a surface 20 feet or more below border tracts. The tributary channels west of it near the head of Bell and Fall creeks are shallower, but many of them have as great width. The valleys or marshy tracts west of New Burlington are also one-eighth to one-fourth mile wide, but they have no definite banks like the tributaries of Prairie Creek and probably have a greater filling with silt. The whole of the Delaware County portion of these channels and the portions within 2 or 3 miles south of the Henry-Delaware county line were apparently either extended northward on the withdrawal of the ice or were formed beneath the ice. Where East White (Blue) River enters this channel it emerges from the moraine and from this point southward has a much greater size than any of the channels formed within the moraine, being nearly one-half mile wide and 40 to 60

feet deep. This greater size does not seem attributable to the accession of the modern stream, but was probably produced by glacial drainage. Throughout Henry, Rush, and Hancock counties the channel is cut deeply into the till tract, but a small part of its bluffs being less than 50 feet and most of them being 60 to 80 feet higher than the broad plain in which the river flows. There is a terrace along this channel, but much of it was removed apparently by the glacial stream, for the channel which emerges from the moraine and which was abandoned with the cessation of glacial floods has a bed which traced southward forms the lower plain along the small stream that now occupies it. The terraces are in all probability the remnants of a gravel-filled channel which was filled by outwash either from an earlier moraine or from the early part of this moraine. The waters that escaped from the margin of the ice as the morainic system approached completion removed a portion of the gravel fillings from the northern part of the channel. In northern Shelby County the terrace descends more rapidly than the lower plain, so that it becomes merged in or buried beneath the later-formed valley drift. The glacial river channel gradually widens from north to south, being one-half mile wide at its emergence from the moraine, a mile or more at the line of Henry and Rush counties, and fully 1½ miles at the line of Hancock and Shelby counties. In Shelby County its width is still greater, but its depth is less, the bordering uplands standing only 15 to 20 feet above the gravel plain. In this county the river has cut a channel in the gravel plain which is very small compared with the glacial flood plain. In southern Shelby County it has cut a valley 15 to 20 feet deep and about one-eighth mile wide in the broad gravel plain. The stream gradually deepens its valley southward, so that at Columbus in Bartholomew County its bed is 30 to 35 feet and its flood plain 25 feet or more below the gravel plain. Features in Shelby and Bartholomew counties have already been described (pp. 70, 77).

The thickness of the gravel in the gravel plain in Shelby County has been ascertained by Mr. David Louden, a well driller residing at Shelbyville, to be 20 to 25 feet at most places and to exceed 40 feet at few. The amount of excavation is, therefore, a channel 40 to 50 feet deep, and this channel has been more than half filled with gravel.

In the upper portion of the East White (Blue) River valley no accurate sections were obtained of wells in the middle of the valley. On the border of the plain at Carthage and Knightstown, wells show 20 to 50 feet of gravel. In most places a heavy deposit of blue till underlies the gravel, but in some rock underlies the gravel. The wells in the valley near Newcastle penetrate about 400 feet of drift, of which only a few feet is surface gravel.

The Sugar Creek gravel plain, which heads in northeastern Johnson and western Shelby counties, appears to have been an outlet for glacial waters at the time the morainic system was forming.

WHITE RIVER BASIN.

The large gravel plain of White River does not head in the White River valley but in the Fall Creek valley, White River being confined in a comparatively narrow valley above Crown Hill in north Indianapolis. The valley of Fall Creek begins to expand near Millersville, about 5 miles above Indianapolis, and within 3 miles its width increases from one-fourth mile to 2½ miles and where it enters White River is fully 3 miles. Below Indianapolis this plain maintains a width of 2 to 4 miles as far as Martinsville, in Morgan County, beyond which it shortly becomes narrower in its passage through the resistant limestone formations.

Above Indianapolis the width of the White River valley is about one-half mile except at some of the bends of the stream, where it is a mile or more. The abrupt enlargement of the valley just above Indianapolis is near the line of the inner edge of the morainic system and seems explainable as the work of a great stream issuing from the ice border. This stream must have started under the ice sheet 3 or 4 miles above the moraine.

From Indianapolis southward to the Johnson County line the moraine is aproned on the west by a gravel plain with basins and other irregularities along the line of junction. That this gravel plain, which stands several feet above a broad terrace of White River, is the product of glacial waters and is not a valley deposit made by White River is shown not only by its close relationship to the moraine but also by its perceptible descent from the moraine riverward. The material appears also to be coarser next the moraine than nearer the river. The western portion of the plain has been removed by White River, but the eastern portion remains intact, with basins along its eastern edge about the morainic knolls. In this portion the excavations reveal comparatively little sand and a large amount of gravel, largely of limestone, like the pebbles of the till.

West of White River, between it and Eagle Creek, is a plain which in places has what appears to be outwash gravels from the moraine. The gravel, however, does not entirely cover the surface, for places were observed where unmodified till crops out at the surface of the plain.

WALNUT CREEK BASIN.

In eastern Hendricks and southern Boone counties the outer border district is a till plain, upon the most level parts of which silty clays nearly free from pebbles range in thickness from a few inches to several feet. It is in this district that channels appear which have already been mentioned as probable lines of glacial or subglacial drainage. The largest channel heads about 2 miles southwest of Lebanon and extends southwestward down one of the headwaters of Walnut Creek for 7 or 8 miles, having too little descent to give the stream a good current. The channel at the north end is about a mile wide, but within 2 miles it becomes narrowed to one-fourth mile and maintains this width downstream for many miles, to enlarge only with the increasing size of

the creek. Near its head it is depressed only 10 to 15 feet below the general level of the bordering plain, but it here occupies a boggy tract which was no doubt deeper when first abandoned. Its bluffs are steep like the banks of a river. This channel is along the westernmost of the Boone County streams that unite to form Walnut Creek. Two other tributaries farther east are characterized by similar channels. The middle of the three passes just west of the village of Milledgeville, below which it is bordered by knolls that rise a few feet above the general upland level, suggesting that both the channel and the knolls may be the product of a subglacial stream.

SUGAR CREEK BASIN.

There is a plane-surfaced gravelly district immediately northeast of Crawfordsville whose relation to the moraine is not clear. It heads just outside a weak moraine which crosses Sugar Creek at Garfield, and may be, in part at least, the outwash from that moraine. The gravel continues westward along Sugar Creek valley past Crawfordsville, but has been terraced by Sugar Creek, the main terrace being about 20 feet below the uneroded tract east of the city.

WABASH RIVER BASIN.

The Wabash seems to have furnished a channel for vigorous discharge throughout the development of the Bloomington morainic system. The gravel plain just west of Williamsport heads in a recess in the outer member. The great Wea gravel plain of western Tippecanoe County, which is about 4 miles wide (including the valley of Wabash River cut in it) and 9 miles long, and which fills the interval between Lafayette and the west line of the county, seems to have been developed during the recession of the ice across the district it covers. Its highest and oldest part is a strip on its south side less than a mile wide and about 3 miles long, which lies about 650 feet above sea level or 150 feet above Wabash River just east of West Point. Its altitude is about 630 feet at the east end and falls to about 615 feet 6 miles to the west, opposite West Point. The material is a fine sandy gravel such as would be expected in a broad plain with a slope of only 15 feet in 6 miles.

INNER BORDER.

From the slope and altitude of the surface the southern tributaries of White River would be expected to run northward to that stream, but they do so only from near Muncie eastward. West of Muncie the streams south of White River run nearly parallel with it. Fall Creek, the largest tributary, flows westward down a slope more gradual than that to the north. Lick Creek, the main tributary of Fall Creek, runs west entirely across Madison County only 2 to .5 miles from Fall Creek and at markedly higher level. Farther south in northern Hancock County the headwater portion of Sugar Creek runs west for 10 miles and then turns south through a depression in the great drift belt. The westward course of these streams may not be difficult to explain, the ice sheet in its lingering withdrawal probably causing the development of streams along its front which persisted after the ice had melted off. No clearly defined moraines along the north side of these west-flowing streams demonstrate this relation to the ice sheet, but the halts may have been too brief for their development. The westward course of the headwater part of White River is not remarkable, for it is in the line of as rapid fall as could have been selected. In Howard, Clinton, Carroll, and Cass counties the prevailing course of drainage is westward down a slope a little more gradual than that northwestward and directly toward the Wabash Valley, and here also it seems probable that the streams were westward along the south edge of the retreating ice, though definite moraines are not present fully to demonstrate this relationship.

In general the west-flowing streams of this region have cut narrow valleys, which deepen toward their mouths and are bordered by abrupt bluffs that stand about at the level of their border plains, but the west-flowing part of White River presents an interesting exception in part of its course. The valley deepens in the usual manner from its headwaters westward to the vicinity of Anderson, where it reaches a depth of 70 or 80 feet. West from Anderson the bluffs become less abrupt and soon drop to 30 feet or less, though within a mile or two back from the stream an altitude of 75 to 100 feet above the river is reached. The slopes are undulatory and some of the swells appear to have been built up by the ice sheet rather than left as a result of drainage erosion. It seems probable that this part of the valley was left as a depression and was only partly filled by drift deposits of the Wisconsin invasion.

Some of the northern tributaries of White River, notably Killbuck Creek, Pipe Creek, and Duck Creek, have valleys with broad undulatory slopes similar to the part of White River valley west of Anderson. Well-defined knolls on the slopes are thought to have been formed by the ice sheet, but the fact that these valleys lead west of south, or about in the direction of ice movement as shown by striæ, renders it somewhat improbable that the undulatory belts mark the trend of the ice margin.

Wildcat Creek west from Kokomo has a valley 40 to 70 feet deep, the depth increasing toward the west. The bluffs are about as high as the land north of the creek, but are lower than the land south of the creek, for the plain rises 10 to 15 feet to the mile from the bluffs southward to the crest of the great drift belt in southwestern Tipton and southern Clinton counties. As a result the tributaries from the south are long and the country they traverse is well drained, but on the north they are trivial and the greater part of the plain for 3 to 5 miles north of the creek in Howard County is poorly drained.

CHAPTER VII.
THE SAGINAW LOBE.

By FRANK LEVERETT.

GENERAL RELATIONS.

The axes of movement of the Lake Michigan, Saginaw, and Huron-Erie lobes converge toward northwestern Indiana, the Lake Michigan movement having been southward in the general trend of the Lake Michigan basin, the Saginaw southwestward through and beyond Saginaw Bay, and the Huron-Erie westward through the Lake Erie basin into Indiana. As a result of the convergence a coalescence, more or less complete, was effected and was maintained until destroyed by a rapid recession of the Saginaw lobe from the district south of the Kankakee. This coalescence has thus far made it unnecessary to make more than a passing reference to the several ice lobes.

A study of the moraines of northern Indiana and southern Michigan (see Pls. VI and VII) has shown that the portion of the ice sheet which moved southwestward from the Saginaw basin into Indiana melted back and disappeared from northern Indiana while the Lake Michigan and Huron-Erie lobes still extended into that State. This perhaps is not surprising, for the path of the Saginaw lobe, especially the part beyond the immediate basin of Saginaw Bay, was across more elevated country than the paths of the bordering lobes. Its thickness must have been correspondingly less and its movement correspondingly weaker, and these differences would become more noticeable with the waning of glaciation and the decrease in the bulk of the ice sheet.

It is somewhat surprising to find that several strong moraines were formed by the Saginaw lobe as it melted back from the border of the Kankakee basin into southern Michigan. Yet this may not be inconsistent with its comparative weakness. The convergence of the three ice movements might, at the culminating part of the Wisconsin stage of glaciation, have caused an excessive loading with drift material in the part of the ice sheet which subsequently became differentiated into the Saginaw lobe. This excessive loading may indeed have been even more influential than the comparative thinness of the ice in bringing about weakness of movement. However this may be, the fact remains that moraines that seem referable to the Saginaw lobe appear at intervals of only a few miles all the way back from the eastern edge of the Kankakee basin across St. Joseph, Marshall, Kosciusko, Elkhart, Noble, and Lagrange counties, Ind., and Cass, St. Joseph, and Branch counties, Mich.

The great line of glacial drainage at the junction of the Lake Michigan and Saginaw lobes, now traversed by St. Joseph River and its tributaries in Kalamazoo, St. Joseph, and Cass counties, Mich., to South Bend, Ind., and beyond South Bend by the Kankakee basin, breaks the continuity of the moraines, and being in a reentrant angle, increases the difficulties of correlating the individual moraines of the two lobes. A peculiar bunching or increase in bulk of moraines on the southeast border of the glacial drainage plain seems to indicate that the influence of the Lake Michigan lobe was felt even on that side. Illustrations are found south of South Bend and Bristol, Ind., and White Pigeon, Mich. As a rule, however, the moraines on the southeast were formed by the Saginaw and those on the northwest by the Lake Michigan lobe.

As a result of the recession of the Saginaw lobe, that part of the ice field came to have a position at the head of a recess between the Lake Michigan and Huron-Erie ice lobes, and it seems almost a misnomer to speak of it as a lobe during this early part of its differentiation. The name “shoulder” might be more appropriate. With further recession into Michigan, however, reentrant angles developed between it and the Lake Michigan lobe on the one hand, and between it and the Huron-Erie lobe on the other, and the application of the term “lobe” becomes fitting. For a time the southern part of the Huron basin and the Erie basin held but a single lobe, the Huron-Erie, which later separated into two lobes, the Huron and the Erie.

The differentiation just suggested is the simplest possible. The actual history may have been more complicated. The border of the lobes, for instance, may have readvanced instead of merely halting at the moraines formed during the recession; complications of this sort, however, are not as yet sufficiently worked out to justify presentation. In the ensuing discussion the reentrant district between the Saginaw and Michigan lobes will first be considered, and then the several moraines—Maxinkuckee, New Paris, Middlebury, Lagrange, Sturgis, and Tekonsha—formed during the withdrawal of the Saginaw part of the ice sheet northeastward into Michigan will be taken up.

REENTRANT DISTRICT.

NEBO-GILBOA RIDGE.

In 1859 attention was called to the Nebo-Gilboa ridge by Richard Owen,[1] who termed two of its prominent knolls Mount Nebo and Mount Gilboa. Notwithstanding the appellation “mount” to these knolls (neither much exceeds 50 feet in height) the ridge is one of the smallest moraines in the State, its width averaging scarcely one-fourth mile and its height about 25 feet.

Throughout Benton County, Ind., the Nebo-Gilboa ridge constitutes the divide between the Illinois and Wabash drainage basins, but in White County it passes into the basin of the Wabash. It has a length of fully 30 miles and fades out in a plain 3 miles northwest of Brooks-ton, Ind. A bowldery strip just south of the eastern end of the ridge, and possibly a dependency of it, continues eastward past Brookston to the Tippecanoe Valley, and there connects somewhat loosely with the Chalmers

kame belt. In its western half the ridge reaches a little above 800 feet above sea level, and Mount Nebo and Mount Gilboa probably reach 850 feet. In its eastern half it gradually descends to about 700 feet. Its surface is gently undulating and it shows a definite crest along nearly its entire length.

The wells on the ridge are mainly through clayey till. Considerable till was found in a well on Mount Nebo, though parts of the knoll are sandy. Mount Gilboa seems to be composed largely of sandy gravel. These two knolls are to be classed as kames. Along the ridge bowlders are common but are not more conspicuous than on parts of the bordering plain.

At the time Monograph XXXVIII was written a ridge in eastern Iroquois County, Ill., now believed to be a continuation of the Nebo-Gilboa ridge, was supposed to be older[2] because of its position west of the great bowlder belt that was thought to mark the limits of the later Wisconsin drift. The bowlder belt, however, more nearly coincides with the border of the Lake Michigan lobe in the reentrant angle between the Lake Michigan and Saginaw lobes than it does in its passage over the Bloomington morainic system to the south. The ridge west of the bowlder belt and reentrant angle is a moraine of the Lake Michigan lobe, and the Nebo-Gilboa ridge is thought to be a correlative moraine formed by ice farther east which later became differentiated into the Saginaw and Huron-Erie lobes. The village of Earl Park, Ind., stands near the place of intersection.

CHALMERS KAME BELT.

The Chalmers belt is best developed within 4 miles east, northeast, and southeast of the village of Chalmers, in White County, Ind., but its kames are scattered over the plain from Chalmers to Tippecanoe River and from near Monticello to the Wabash Valley southeast of Brookston and a few are east of Tippecanoe River near Monticello. The knolls are sharp and rather closely aggregated near Chalmers, but near the Tippecanoe are separated by flat tracts of considerable extent. The highest knolls rise 50 to 60 feet above the bordering plains, and knolls 20 to 30 feet high are numerous. So far as can be determined by exposures in gullies these knolls are composed largely of fine sandy gravel with only local beds of cobble or coarse material. Bowlders are not so numerous as on the bordering plain.

[1]Ann. Rept. Indiana Geol. Survey for 1859, 1860, p. 219.

[2]The Illinois glacial lobe: Mon. U. S. Geol. Survey, vol. 38, 1899, p. 258.

When first examined by Chamberlin and the writer in 1886 and 1887 this kame belt was thought to have been formed on the western edge of the Erie ice lobe after the ice had withdrawn from the Iroquois basin. By means of bowldery strips and scattered knolls it can be connected toward the northeast with a strong moraine, also thought to be a product of the Erie lobe. The failure to find any definite continuation toward the south left the interpretation somewhat in doubt. The region was reexamined by the writer and by A. H. Purdue in 1895 in connection with other studies in that region and was visited again by the writer in 1902. The correlation can not be said to be fully settled yet, but it now seems probable that the kame belt was formed while the ice covered the territory west as well as east of it, and it may be a correlative of the Nebo-Gilboa ridge. This kame belt and the bowldery tracts that extend northeast from it across northwestern Carroll County are thought to mark the junction of ice movement from the Erie and Saginaw basins before distinct lobes appeared in the process of the melting away of the ice. The evolution of the lobes is brought out step by step in the discussion of later moraines.

The continuation of the border of the Erie lobe across the Wabash seems likely to be found in a strip of gently undulating land with numerous basins that leads from Delphi southeastward past Flora to Wildcat Creek at Cutler, where it develops locally into a rather pronounced moraine. It was formerly thought that the ice border may have taken a southward course from near the mouth of the Tippecanoe along a bowldery belt on the east side of Wabash River and thus made connection with the moraine and bowlder belt a few miles east of the city of Lafayette. Owing to the poor development of morainic features in the district east of the Wabash, the mapping and interpretations must necessarily be somewhat indefinite.

BOWLDERY AREAS.

Bowlder-strewn areas are common on till plains in southern Jasper and western White and Pulaski counties, as well as in the vicinity of the Chalmers kame belt. They are not so numerous on the till plain of the immediate border of Iroquois River. Considerable time was spent in mapping these bowlder belts by Chamberlin in 1886 and by Purdue and the writer in later years, it being thought that their distribution might throw light on the manner in which the ice disappeared from the region. But though belts of considerable length were found no system in their distribution was detected. They trend in various directions and are especially abundant where surface sand is thin or wanting; indeed, they fade out as sandy areas are approached. Throughout much of the district bowlders are numerous where the bedrock is within a few feet of the surface, but they are also present where the drift is thick. It seems doubtful, therefore, if high altitude of rock surface was of much importance in determining their lodgment. Their distribution was probably determined by somewhat indefinite conditions within or upon the ice sheet in its vanishing stage.

As is common in belts along moraines the bowlders differ in kind and size and degree of angularity. The majority are granite, but many are of other rock types, among which are a red jaspery conglomerate apparently derived from Huronian ledges north of Georgian Bay, and a greenish conglomerate containing granite pebbles. Few are representatives of local rock formations. Many

are 2 feet or less in diameter and few exceed 4 feet. They range from well rounded to sharply angular, the rounding appearing to have been produced by weathering rather than by water action. The absence of striated or glacially planed surfaces on all but a few of the bowlders distinguishes them from rocks included in the drift, many of which show glacial planing and striation.

MARSEILLES MORAINIC SYSTEM.

COURSE AND CORRELATION.

In Monograph XXXVIII the Marseilles morainic system of the Illinois lobe was traced as far east as the village of St. Anne, Ill., a few miles southeast of Kankakee, and it was noted that its natural continuation lay eastward along a ridged belt and bowldery strip north of Iroquois River in Newton and Jasper counties, Ind., to which the name “Iroquois” moraine was applied. It was suggested that this “Iroquois” moraine is the result of two ice advances differing widely in date as well as in direction, one advance being from the north in the earlier Wisconsin substage, and the other from the south or southeast in the later Wisconsin substage. Much of the relief along the moraine was ascribed to the earlier advance, and only the bowlders and the low knolls on its surface were considered to be the product of the later one. As an alternative it was suggested that the moraine might stand in the line of an interlobate spur formed at the junction of the Illinois and Erie-Saginaw lobes, and that the numerous bowlders are a result of this interlobate condition. The date of the formation of this interlobate spur was placed in the later Wisconsin substage.

It now seems necessary to suggest another interpretation, namely, that the “Iroquois” moraine is simply the continuation of the Marseilles morainic system and was produced entirely by the Illinois lobe. This is the simplest interpretation of the three and seems to be the best supported, for the others lack the evidence necessary fully to establish the complex history postulated for them. If the “Iroquois” morainic tract be examined in cross section it is found to resemble the Marseilles in amount of relief, in breadth, and in having a long gradual slope on its north or iceward side, and a rather abrupt descent on its south or landward side. The rise from the plain to the crest of the moraine on the north amounts to 20 to 40 feet in about 2 miles and on the south to 30 to 50 feet in less than 1 mile. These similarities and the further fact that the “Iroquois” moraine lies in the line of natural continuation of the Marseilles system strongly favor the third view.

The width of the “Iroquois” moraine is generally between 2 and 4 miles, but bowldery areas on its north border extend about 2 miles farther north to the southern edge of an extensive sandy plain traversed by Kankakee River.

The southern border of the “Iroquois” moraine lies 1 to 4 miles north of Iroquois River in Newton and Jasper counties, Ind., and trends south of west and north of east. In eastern Jasper County it turns northward and extends nearly to the northeast corner of the county. It dies out as a definite ridge 4 or 5 miles south of Kankakee River, and its continuation to the east is uncertain.

Inasmuch as this moraine dies out at the northeast in a sandy plain, some uncertainty is felt as to its continuation farther east. One possible correlative is a moraine which begins near Bass Lake, in Starke County, about 18 miles to the east. Between the two lies a tract which, though generally sand covered, bears a broad low ridge from the north end of the “Iroquois” moraine at San Pierre to North Judson and carries patches of bowlder-strewn till from North Judson to Bass Lake, thus nearly filling in the interval between the ends of the well-defined moraines and giving some strength to the correlation. The correlative moraine, which leads southeastward from Bass Lake, appears to have been formed by the Saginaw lobe, for it lies on the immediate outer border of the great Maxinkuckee moraine of that lobe, discussed below.

TOPOGRAPHY.

The highest points noted on the Marseilles system in the district north of Iroquois River are north of Rensselaer, where an altitude of 765 to 775 feet above sea level is attained. Much of the moraine reaches between 700 and 725 feet.

The surface of the ridge carries low knolls and ridges, among which sloughs and shallow basins are inclosed. Part of the bowlder-strewn plain north of the ridge is also occupied by low swells and hummocks, among which are shallow basins, but much of it is flat.

STRUCTURE OF THE DRIFT.

The depth to rock is only 40 to 50 feet in the northeastern part of the moraine from near San Pierre to Kankakee River, but increases to nearly 100 feet within a few miles south of San Pierre and on the high part of the moraine north of Rensselaer has not been reached by some wells nearly 200 feet deep. The general depth from Rensselaer westward is about 125 feet.

The basal portion of the drift is an indurated till, 35 to 40 feet thick, probably of pre-Wisconsin age. Above it is a very clayey, easily penetrated till, which is thought to be Wisconsin drift, and which forms the body of the ridge and gives it relief above the bordering plains. The surface portion to a depth of 5 to 20 feet differs markedly from the underlying clayey till, showing many abrupt changes from sand to clay. The sand has a somewhat singular distribution, capping many of the knolls to a depth of a few feet and being absent from many of the contiguous lower tracts. Northward from the ridged portion of the moraine across the bowlder-strewn plain sand patches become more and more noticeable until they coalesce in a continuous sheet. Bowlders abound in .portions of the ridged part and are common over the entire ridge; they occur, however, in greatest number on

the plain north of the ridge. Most of them are of granite and other crystalline rocks of Canadian derivation, but many are limestone fragments of local derivation. In an excavation at Brook, just south of the moraine, a collection of pebbles 1½ inches or less in diameter, taken in order as they appeared on the slope, was made up of the following rocks:

Pebbles in till near Brook, Ind.

Limestone, chiefly gray	56
Shale, sandy	4
Chert, probably from the limestone	3
Quartz	2
Granite	6
Greenstone	8
	79

Several wells along the ridge and in the border plain pass from soft, easily excavated till of Wisconsin age to hard, partly cemented till, probably of Illinoian age. North of Rensselaer, in sec. 30, T. 30 N., R. 6 W., two wells reach the bottom of the soft drift at 90 feet, and a third at 97 feet. The first two were extended through a hard till to water-bearing sand at 130 and 147 feet, but the third found water between the two sheets of drift. South of the moraine, in the vicinity of Brook, a soft till extends to a depth of 50 or 60 feet, below which a harder till extends either to the rock or to water-bearing beds. About 5 miles northwest of Kentland, in sec. 13, T. 27 N., R. 10 W., four wells on the farm of J. V. Speck are reported to have passed, at about 80 feet, through a brown swamp muck representing an old land surface at the bottom of the till, beneath which they entered water-bearing sand and gravel. In the vicinity of Donovan, Ill., several wells pass, at about 100 feet, from soft into hard till, below which, at about 140 feet, lies black muck, underlain by another till sheet. Records of several wells along the line of the ridge make no mention of a change from soft to hard till at depths corresponding to those just reported, but this lack may be due to less close observation. The thickness of the drift approaches 200 feet in some of the wells.

A well on Mr. Peterson's farm near the State line, in sec. 11, T. 28 N., R. 10 W., on a high part of the moraine, penetrated 168 feet of drift, of which the lower 8 feet was water-bearing sand and the remainder till. A neighbor's well 171 feet deep passed through 165 feet of till before striking water-bearing sand.

At Morocco, on the north slope of the moraine, a boring at the creamery penetrated 127 feet of till to limestone. Several wells near the range line east of Morocco enter rock at 110 to 120 feet after penetrating a solid bed of till.

At Mount Ayer, also on the moraine, a few wells put down to 140 to 160 feet extend but little into rock. The drift in Mr. Ashby's well has the section given below, Lewis Marion's strikes shale rock at 139 feet, and W. J. Young's at 150 feet, the wells being mainly through till to these depths.

Section of drift in Ashby well at Mount Ayer, Ind.

	Feet.
Till, yellow	10
Sand, blue	20
Till, blue	90
Shale, blue	20
Rock, hard, flinty.	
	140

Two wells at Surrey that enter rock at 90 feet are mainly through till. Several borings 2 or 3 miles north of Surrey strike rock at 80 or 90 feet. On the crest of the moraine southeast of Surrey at Charles Coen's, in sec. 12, T. 29 N., R. 7 W., a well strikes rock at 192 feet and there obtains water. At William Nowel's, in the same section, a well strikes rock at 140 feet and obtains water at 162 feet. In both wells the drift is mainly till.

A well on the moraine southwest of Medaryville, in sec. 13, T. 30 N., R. 5 W., penetrates 102 feet of drift, mainly blue till; another in the same section penetrates 80 feet. A well at Mr. Osborne's, in sec. 1 of the same township, has 126 feet of drift, and one at Mr. Rayburn's, in sec. 2, has 118 feet. A well at the tile factory in Medaryville passed through 92 feet of drift and obtained water from the rock at 115 feet. A prospect boring for gas shows the drift at North Judson to be 198 feet thick.

From North Judson a heavy body of drift extends eastward across northern Indiana. The rock surface appears to be somewhat lower along the line of this moraine than a few miles south of it, for the drift is very thin in southwestern Pulaski and in much of southern Jasper and Newton counties. The rock also appears to be higher north of the moraine in a small tract near the corners of Starke, Jasper, Porter, and Laporte counties, several oil wells having entered it at 50 feet or less.

SAND OF KANKAKEE-TIPPECANOE AREA.

The sand of the Kankakee-Tippecanoe area was discussed in Monograph XXXVIII as a deposit of Lake Kankakee, though it was pointed out that the "lake" seemed to consist not of any general body of water, but merely of small shallow marshlike areas not very different from those of the present Kankakee Marsh. It was suggested by Chamberlin[1] that the great accumulations of sand are probably referable to outwash from adjacent ice lobes, the Lake Michigan lobe bordering the area on the north and the Erie-Saginaw lobe on the east. Subsequent investigations have sustained this idea and have brought out evidence that points to a northward and eastward enlargement of the sand area during the recession of the ice lobe. The existence of certain low-lying tracts strewn with bowlders and nearly free from sand amid bordering higher sand-covered areas suggests that patches of stagnant ice persisted while the sand was being laid down. By the time the stagnant ice had disappeared the deposition of the sand seems to have been practically completed in much of the area south of the Kankakee Marsh.

If the deposition of the sand was progressive, it probably began along a belt which runs westward for 20 miles from Monticello through White and northern Benton counties, nearly parallel with the Nebo-Gilboa ridge and distant from it scarcely 3 miles. It has in places the

narrow, definitely ridged form of a shore line, being 100 to 200 yards in width and 10 feet or less in height, but it varies in altitude in a manner inconsistent with its being a shore feature. It ranges from 675 up to fully 750 feet above' tide, rising from Monticello westward to about the meridian of Goodland and beyond that point descending to a western terminus near Kentland nearly as low as its beginning at Monticello. Its parallelism to the Nebo-Gilboa ridge suggests that it is an ice-border feature formed probably in a manner similar to an outwash apron. The higher land to the south would prevent the spread of the sandy outwash beyond the immediate edge of the ice, and thus account for the narrowness of the sand belt. Some of the ridging may have been produced by wind action.

[1]Preliminary paper on the terminal moraine of the second glacial epoch: Third Ann. Rept. U. S. Geol. Survey, 1883, p. 330.

On theoretical grounds it seems probable that ponded conditions prevailed in the district south of the Marseilles morainic system during its development. The basin now drained northward by Iroquois River into Kankakee River would have been prevented by the ice sheet from draining in that direction, and it probably discharged across a low point on the western rim of the basin to the east fork of Vermilion River in northern Ford County, Ill.[1] The distribution of the sand deposits in the Iroquois basin lends support to this interpretation. A sand ridge leading through Onarga and Ridgeville, Ill., at an altitude of about 675 feet above sea level, is thought to mark the southern edge of the lake in the western part of the basin and to indicate its height. There may also have been an eastward discharge from the basin past Monon, Ind., into Monon Creek and thence to Tippecanoe and Wabash rivers. A long sand ridge leading eastward from the meridian of Goodland, Ind., nearly to Monon stands at about 675 to 680 feet and probably marks the southern edge of the lake. Nearly all the sand in the Iroquois basin is below the level of these sand ridges, and the portion above does not conform to the conditions of a lake shore. Its ridges rise and fall in their course across the country and seem to have been developed by wind rather than by water. In places a fine silt has been deposited within the area supposed to have been covered by the lake; one such locality was noted a few miles southwest of Rensselaer, Ind., and another in Iroquois County, Ill., between Watseka and Donovan.

Sandy areas farther east in the district between Monon Creek and Tippecanoe River, like those east of the Tippecanoe in Pulaski and White counties, were probably laid down in connection with the recession of the Erie-Saginaw portion of the ice sheet. The headwater portion of Monon Creek is in a bowlder-strewn basin nearly surrounded by slightly higher sandy tracts. This basin, which occupies an area of about 25 square miles, may perhaps have held a mass of stagnant ice during the deposition of the surrounding sand deposits. Similar depressions near Winamac and above that village along the borders of Tippecanoe River seem to mark places where the ice persisted during the deposition of sand over the bordering district. Some small areas free from sand in southeastern Starke County, both southwest and west of Bass Lake, may perhaps be explained in the same way.

Outside of the Valparaiso morainic system and its gravel outwash the Kankakee basin is covered by sand except over a small area in southwestern Starke and northeastern Jasper counties where a bowldery till forms the surface. The altitude of this till area is between 660 and 670 feet, somewhat lower than that of the surrounding sand-covered tracts and 30 to 40 feet lower than that of the sand 2 or 3 miles to the south. As in the districts to the east, the absence of the sand from this low tract may be due to its occupation by ice during the deposition of the sand.

Considerable attention has been given to the slope of the sandy tracts with a view to determining the direction in which the waters probably flowed. In the Kankakee basin they seem to have flowed westward from the time the Lake Michigan ice lobe shrank away from the southern edge of the valley. In the Iroquois basin they probably flowed westward, though, as just indicated, they may have been ponded to some extent south of the Marseilles morainic system. In the Tippecanoe basin conditions are more complex: The river flows chiefly among moraines for more than half its length before entering this sand area. At its point of entry near Ora (see PI. VI) it is closest to Kankakee River. From this point the sandy plain slopes northwestward toward the Kankakee as well as southwestward into the territory traversed by the Tippecanoe, forming a very flat alluvial cone. This suggests a spreading of drainage from this part of the Tippecanoe during the height of the glacial floods. The present stream for some 25 miles below Ora takes a zigzag course through a series of bowlder-strewn depressions which the sand did not fill and which, as already suggested, may have been occupied by remnants of the ice sheet during the deposition of the sand. The sand on the western side slopes away from the river toward Monon Creek, continuing the southwestward slope it had on the eastern side. Thus Monon Creek, although a tributary of the Tippecanoe, flows through a district lower than that of the main stream. The divide between Monon Creek and the headwaters of the Iroquois is very low and flat, especially south of the Marseilles morainic system, and the general southwestward slope is continued into the Iroquois basin. The valley of the creek, however, is a broad slough which, like the depressions along the Tippecanoe below Ora, has diverted the drainage to a course out of harmony with the general slope. It seems probable, therefore, that from much of Pulaski County now drained southward there was a southwestward glacial drainage to the Iroquois and that from near Ora in Starke County there may have been a northwestward drainage to the Kankakee as well as a southwestward drainage to the Iroquois. Below the junction of Monon Creek and Tippecanoe River there may have been a southward drainage to the Wabash, but if so it seems not to have distributed the sand far in that direction,

unless along the immediate valley of Tippecanoe River. Possibly the lower course of the Tippecanoe was still occupied by the Erie lobe and drainage in that direction was prevented until the deposition of the sand was essentially completed.

[1]Leverett, Frank, The Illinois glacial lobe: Mon. U. S. Geol. Survey, vol. 38, 1899, pp. 289-290, 314.

Throughout this area the sand is generally free from coarse pebbly material and appears, therefore, to have been deposited by streams with rather sluggish currents, as would be expected from their very gradual descent and their great breadth. The present Kankakee, from its source near South Bend to the State line of Indiana and Illinois, descends about 15 inches to the mile, yet because of its breadth in the marsh it is capable of transporting only fine sand. The slope of the Kankakee Marsh, however, appears to be greater than the average slope in the parts of the Tippecanoe and Iroquois drainage basins where the sand was deposited.

The depth of the sand probably corresponds to its relief above the bordering clay plains (10 to 25 feet, with an average of perhaps 15 feet), for wells find water in it at about the level of the clay. Along the Kankakee Valley sand appears to be heavier as well as more extensive than in the Tippecanoe and Iroquois basins. It is thought that much of the sand was brought into the Kankakee basin by glacial streams that discharged through St. Joseph River during the recession of the ice into southern Michigan, and that it was thus collected from a much larger area than that tributary to sand-covered parts of the Iroquois and Tippecanoe basins.

Some weak morainic ridges along the eastern edge of the sand-covered area come up for consideration more naturally in connection with the Maxinkuckee moraine, with which they seem to have close relations. (See p. 132.) The extensive outwash apron of gravel and sand north of the Kankakee is also more appropriately considered in connection with the morainic systems of the Lake Michigan lobe in that region. (See pp. 175, 180.)

STRIÆ.

Observations on striæ made by Chamberlin at Monon and near Kentland, indicate two ice movements, an earlier one southward and a later one westward. The later movement fits in well with the Wisconsin and is probably referable to it, and the earlier or southward movement may be Illinoian. Southward-bearing striæ found at Rensselaer may also have been formed prior to the Wisconsin ice invasion.

MAXINKUCKEE MORAINE AND ASSOCIATED GLACIAL FEATURES.

COURSE AND DISTRIBUTION.

A great belt of very irregular-surfaced drift 5 to 15 miles wide leads southward from, South Bend about 40 miles to the Tippecanoe Valley opposite Rochester, Ind. Except at its northern end, which may have been touched by the Lake Michigan lobe, it seems to have been formed by ice that lay on its east side. The moraine takes its name from Lake Maxinkuckee, which stands in its broadest part a few miles northwest of Rochester.

The great breadth of the moraine in the vicinity of Tippecanoe River compared with its breadth near South Rend indicates that the ice was not holding its position in the former locality so firmly as in the latter. South of the Tippecanoe the recession seems to have been still more rapid; well-defined moraines are wanting, only narrow strips and interrupted patches of undulating land .interrupting an otherwise flat-surfaced country. The recession probably extended across the entire breadth of Fulton County into southern Marshall and western Kosciusko counties during the development of the well-defined ridge north of Tippecanoe River. It was by this rapid recession in the district south of the Tippecanoe that the Saginaw lobe became differentiated from the Erie.

The best defined of the weak undulating strips leading southward from the Tippecanoe Valley passes east of south along the east side of Bruce Lake to Kewanna, where it swings around toward Royal Center and runs west of south to the Wabash Valley at Lake Cicott, about 10 miles west of Logansport. From Lake Cicott it is probably continued westward by a line of bowldery ridges leading past Idaville and dying out east of Monticello. Kewanna stands in a reentrant that apparently marks an incipient separation between the Saginaw and the Erie lobes, for the portion of the moraine to the south conforms more nearly with the trend of a moraine of the Erie lobe lying north of the Wabash than with the moraine of the Saginaw lobe under discussion.

A still weaker belt of undulating drift, a few miles west of the one just outlined, leads off southwestward to Thornhope and marks a still earlier position of the Erie lobe. The Saginaw equivalent seems to be found in ridges northwest of Bruce Lake in the bend of Tippecanoe River near Ora.

A ridge connects at the southeast with the Maxinkuckee moraine west of Lake Maxinkuckee, but leads away from it northwestward to Bass Lake in Starke County. It is 1 to 1½ miles wide and seems to mark a position held by the ice before the reentrant between the Saginaw and Lake Michigan lobes had receded to the head of Kankakee River. It may prove to be a correlative of the Marseilles morainic system of the Illinois lobe (p. 126).

The continuation of the inner or eastern portion of the Maxinkuckee moraine probably embraces a gently undulating tract north of Tippecanoe River in southern Marshall County. On entering Kosciusko County it passes to the south side of the river and forms a chain of weak ridges lying north of Burkitt. It connects with a large moraine of the Erie lobe near Claypool, a few miles south of Warsaw.

On the north border of this gently undulating tract a disjointed, narrow morainic ridge about 40 miles long, known as the Bremen moraine, runs past Bremen, Heckton, and Millwood and connects with the Maxinkuckee moraine at its northwest end near Lakeville and with the moraine of the Erie lobe at its southeast end near Warsaw. The country is decidedly flatter to the north of this ridge than to the south, so it gives a definite inner limit to the Maxinkuckee moraine and associated undulating tracts.

TOPOGRAPHY.

MAIN RIDGE NORTH OF TIPPECANOE RIVER.

In the district north of the Tippecanoe the Maxinkuckee moraine is topographically conspicuous from the plain that borders it on the west. The plain has an elevation of 720 to 750 feet along the border of the moraine. The moraine is largely above 800 feet and has points that closely approach 900 feet, the altitude at Penn geodetic station, 3 miles southeast of South Bend, being 897 feet and at a railway summit 4 miles south of Argos 887 feet. The region around Lake Maxinkuckee falls a little below 800 feet in general elevation, but ranges from 650 feet in the deepest part of the lake to 875 feet on the highest hills east of the lake.

Although so prominent from the outer border the moraine is relatively inconspicuous from the inner border, and grades, in Marshall County, into a gently undulating tract that stands nearly as high as the crest of the moraine.

Considerable variety of expression is found along the main belt between South Bend and Tippecanoe River. From the St. Joseph River bluff at South Bend southward to Potato Creek, a distance of 10 or 12 miles, many knolls rise abruptly to heights of 50 or 60 feet; among them are inclosed basins and sloughs. Prom Potato to Pine Creek, a distance of 10 miles, swells are usually 20 feet or less in height and the slopes gentle; shallow basins, however, are numerous. The expression is somewhat stronger toward the inner or eastern border than along the outer border. Pine Creek and streams near it are bordered by broad marshy tracts that give the outer edge of the moraine a ragged outline. The interfluvial tracts show an increase in ruggedness southward from Pine Creek, and opposite Plymouth knolls 30 to 50 feet in height appear.

North of the outlet of Twin Lakes, in sec. 18, T. 33 N., R. 1 E., a gravel knoll rises abruptly about 100 feet above the level of the outlet. A gently undulating tract between Twin Lakes outlet and Yellow River grades into an outwash apron. Some of the knolls bordering Lake Maxinkuckee rise 75 feet above the lake and 30 to 50 feet above low tracts on the east. The moraine is most prominent on the north and east sides of the lake. A few miles east of Lake Maxinkuckee, just north of the village of Walnut, a small tract contains several knolls 30 to 40 feet high with interspersed basins and sloughs. The common topography, however, in southern Marshall and northern Fulton counties is less sharply morainic, most of the swells and ridges being but 10 to 25 feet high, and basins are uncommon.

The weak outlying morainic belt in the southeastern part of Starke County has a few knolls 25 to 30 feet high, interspersed with tracts of gentle undulation and broken for about 1½ miles midway of its length with a gap filled with sand ridges. Although weak when compared with the Maxinkuckee moraine this moraine is in striking contrast to the bordering plains on which there are no knolls.

MAIN RIDGE SOUTH OF TIPPECANOE RIVER.

The undulating belt south of the Tippecanoe has few if any points exceeding 800 feet, most of it being between 760 and 800 feet, and is relatively inconspicuous from either side. Though its surface is decidedly more undulatory than that of the bordering plains, knolls exceeding 25 feet in height are rare, the majority being but 10 to 15 feet. In the feeble outlying belt south of the Tippecanoe the highest knolls reach about 20 feet and many are scarcely 10 feet high. They are on the whole less conspicuous than the outlying sand ridges.

In northern Cass and southern Fulton counties a bowldery belt lies in a plain as smooth as that on either side, swells 10 feet in height being rare. Its altitude, however, is high, being about 800 feet. For some miles it follows the divide between Eel River on the south and Tippecanoe River on the north. From its northeastern end northward to Rochester the undulation is greater, swells 10 to 20 feet high being common, and a sharp ridge in secs. 16 and 21, T. 30 N., R. 3 E., reaches about 40 feet.

INTERMORAINIC DISTRICT.

In the district between the main ridge and the Bremen moraine swampy basins or depressions are numerous, probably one-fourth of the surface being occupied by them. Most of the dry land has a wavy or gently undulating surface. Most knolls are but 10 or 12 feet high and few of them reach 20 feet. The features are such as might result from a rapidly receding ice border. The most prominent ridge noted is one just west of Atwood, in western Kosciusko County. It rises about 40 feet above surrounding country, is a mile in length, and nearly one-half mile in width. A cut in its northeast end, made by the Pittsburgh, Fort Wayne & Chicago Railway (Pennsylvania Railroad), is 25 feet in depth, and the roadbed of the railroad is raised slightly to pass through it.

STRUCTURE OF THE DRIFT.

COMPOSITION.

In the district north of the Tippecanoe, not only in the main moraine but in the gently undulating tract east of it, the drift is largely of gravel and sand or of sandy till. The part between South Bend and Potato Creek shows abrupt changes from gravel to till, knolls largely composed of gravel standing next to knolls largely composed of till, and some single knolls showing abrupt changes from gravel to till. The portion of the moraine between Potato and Pine creeks is composed more largely of clayey till than any other equal-sized area north of the Tippecanoe. From Pine Creek southward past Twin Lakes and Lake Maxinkuckee gravel and sand are commonly found in knolls in association with loose-textured till. East of Lake Maxinkuckee some clayey till is found, but as a rule the drift is loose textured and more or less gravelly.

BOWLDERS.

Surface bowlders are numerous north of the Tippecanoe, averaging perhaps 1,000 to the square mile on all the dry land of the district. They seem fully as abundant on the gently undulating tract between Tippecanoe and Yellow rivers as on the Maxinkuckee moraine but are rare in the swamps, perhaps because buried underneath the muck and organic growths. Most of them are of granite, but a very few, not more than a fraction of 1 per cent of those exposed, are of a red, jaspery conglomerate. They are generally small enough to be easily gathered up or buried by the residents, their common diameter being 2 to 3 feet.

In the district south of the Tippecanoe the drift in the undulating belts as well as in the plains is largely a clayey till. It is not rare, however, to find small knolls and ridges of sand or sandy gravel on prominent points or capping till swells. Few, however, contain gravel suitable for road ballast, and some seem to contain no pebbles.

South of the Tippecanoe bowlders are abundant only in certain belts, one running southward to Kewanna from the Tippecanoe Valley, and another running northeast and southwest through southern Fulton and northern Cass counties. (See Pl. VI.) In the former bowlders are no more conspicuous than in the district north of Tippecanoe River; in the latter they are much more numerous, numbering several thousand to the square mile. Granite far outnumbers all other kinds. The common diameter, as in the district north of the Tippecanoe, is 2 to 3 feet; those exceeding 5 or 6 feet are rare.

THICKNESS.

Depth to rock.—In the district occupied by the Maxinkuckee moraine and associated bowlder belts and undulating tracts the drift is very thick. The least thickness reported is 90 feet (at Royal Center) and the greatest thickness may exceed 300 feet. Reported thicknesses are set forth in the following table:

Deep borings on or near Maxinkuckee moraine.

Location.	Altitude of surface.	Thickness of drift.	Altitude of rock surface.
	Feet.	*Feet.*	*Feet.*
South Bend	725	137	588
Plymouth	780	242	538
Lake Maxinkuckee (Moorman boring)	734	203+	531 or less.
Rochester	800	155	645
		245	555
Warsaw	824	255	569
		247	577
Warsaw, 3 miles west of	820±	243	577±
Kewanna	785	167	618
		208	577
Royal Center	734	90	644
		109	625

If the rock surface has the same altitude beneath the Penn geodetic station, 3 miles southeast of South Bend, as at South Bend the thickness at the former place is over 300 feet. If it is the same on the crest of the moraine west of Plymouth as at Plymouth the thickness is about 300 feet.

If the rock is as low under the hills east of Maxinkuckee Lake as in the Moorman boring at the lake, the drift on the hills exceeds 324 feet, for the Moorman boring on ground only 20 feet above lake level failed to reach rock at a depth of 203 feet.

Probably a considerable part of the drift was deposited before the Wisconsin stage of glaciation, but the data concerning the character of this deeper part are insufficient to fix its contact with the Wisconsin drift.

The relief of the moraine above the districts to the west seems to be entirely due to Wisconsin drift, and this would justify the reference of between 50 and 100 feet of drift to this latest stage of glaciation. The depth of Lake Maxinkuckee (80 to 90 feet) carries its bed below the level of the plain outside the moraine and suggests that considerable filling may have occurred on the plain as well as on the moraine and that somewhat more than 100 feet of drift was deposited at the last glaciation. The difference in level between the bed of Lake Maxinkuckee and the highest hills east of the lake is 225 feet, and possibly these hills were built up at this latest stage from a level as low as the lake bed.

Flowing wells.—Flowing wells are obtained in the low tracts along the moraine from Lake Maxinkuckee northward. They are reported to pass through considerable clay before entering the bed from which the flows are obtained. Data were obtained in five distinct districts—around Lake Maxinkuckee, in Yellow River valley at Plymouth, near Teegarden on a low part of the moraine, in Potato Creek valley east of North Liberty, and in the St. Joseph Valley at South Bend.

The flows around Lake Maxinkuckee are obtained at various depths from 13 feet up to about 100 feet. The following record of A. H. Culver's well[1] illustrates the structure of the drift in one of the deeper wells:

Record of Culver well.

	Feet.
Soil and yellow clay	8
Sand	14
Clay, blue	38
Sand and gravel	12
	72

Another boring, 98 feet deep, passed through yellow clay 11 feet, sand 25 feet, blue clay 62 feet, and failed to reach the bottom, the flow being from sand above the clay. The Peru Club sunk a well to a depth of 160 feet

and stopped in "obdurate hardpan;" it obtained a weak flow from a sand bed higher than the hardpan. The deepest boring of which the present writer obtained data was sunk by D. W. Morman to a depth of 203 feet, obtaining a flow at about 100 feet. The head is reported[2] to be sufficient in parts of the basin to carry water 31 feet above the lake (765 feet above sea level), but in the Morman boring the water stands 13 feet below the surface and only 7 feet above the lake. The various depths at which the flows are obtained and the difference in head and strength of flow indicate that the bedding and texture of the gravel of the drift are very irregular.

In the flowing wells at Plymouth the depth to the water bed is about 40 feet, but some wells are carried deeper. Records furnished by a driller indicate little besides sand, interspersed with beds termed "hardpan," 2 to 5 feet thick.

In the Teegarden district, which extends down Yellowbank Creek 2 or 3 miles from Teegarden, the wells are mainly through blue till and range in depth from 40 feet to about 100 feet.

In Potato Creek valley east of North Liberty two flowing wells, 45 and 70 feet deep, were reported to be largely through till. A well on the gravel plain about a mile southwest of North Liberty, in sec. 5, T. 35 N., R. 1 E., is reported by the driller to be entirely through sand and gravel to a depth of 160 feet. The water heads 1½ feet below the surface.

In the St. Joseph Valley at South Bend flowing wells have been obtained for the waterworks supply from sand underlying a bed of stiff clay reported to be nearly pebbleless. There were at the time of the writer's visit in 1902 thirty 6-inch wells about 100 feet deep, with head 5 or 6 feet above the surface and yielding by pumping at least 10,000,000 gallons a day.

The gas boring made by Mr. Oliver at South Bend is reported by Phinney to have penetrated the following drift beds: Sand, 25 feet; gravel, 20 feet; clay, 30 feet; sand, 25 feet; gravel, 37 feet.

Deep wells.—Records of several other wells of considerable depth were obtained. Two, on a prominent part of the moraine about 8 miles from South Bend, in sec. 17, T. 36 N., R. 2 E., are 131 and 146 feet deep; neither reaches rock. A well on the farm of Mr. Sweeney passed through 22 feet of yellow till, a thin bed of sand, and blue till and sand in alternate beds a few feet thick to the bottom of the well.

[1]Fifteenth Rept. Indiana Dept. Geology and Nat. Hist., 1887, p. 184.

[2]Idem, p. 185.

The gas boring at Plymouth which extended some depth into rock penetrated 240 feet of drift as follows: Sand and gravel, 40 feet; till, 50 feet; mainly sand and gravel, 150 feet.

Records of two wells west of Lake Maxinkuckee, in the eastern edge of Starke County, show contrast in drift structure. One on the farm of David Fetter, in sec. 13, T. 32 N., R. 1 W., penetrated sandy till, 5 feet; blue till, 12 feet; quicksand, 5 feet; blue till, 30 feet; sand and gravel, 2 feet. The other, on the Pettis farm, in sec. 24, penetrated soil and yellow till, 12 feet; blue till, 16 feet; gray sand, 52 feet; blue clay, 4 feet; cemented sand and gravel with perhaps some clay, 15 feet.

West of the wells just noted, past Bass Lake to Round Lake and Aldine, blue clay is present at slight depth in many of the wells. Bowlders are also conspicuous from Lake Maxinkuckee westward to Bass Lake on nearly plane tracts and on morainic tracts.

A boring at Bremen, in the west part of the village, reached a depth of 100 feet, mainly through blue till. The common depth of wells at Bremen is 30 to 40 feet, largely through till.

At Inwood wells are mainly through sand and gravel or sandy till, though thin beds of "clay" are reported to occur.

Records of gas borings made some years ago at Rochester show alternations of till with sand and gravel, but give no details of structure.

Gas borings at Kewanna penetrated considerable sand and gravel and some thin beds of blue till. Farm wells in the vicinity of Kewanna pass through considerable blue till; one in sec. 28, T. 30 N., R. 1 E., is 120 feet deep, but most of them are less than 50 feet deep.

At Royal Center oil wells penetrate 90 to 109 feet of drift. In some wells gravel between the surface clay and the blue till yields water at a depth of 10 feet or less. Other wells penetrate about 40 feet of blue till to reach a lower gravel bed at 50 feet. The oil-well borings are reported by Elrod to have passed through "gravel mixed with yellow clay" in the lower part of the drift. Two deep farm wells east of Royal Center, reported by Elrod, show considerable contrast in drift beds. One in sec. 21, T. 28 N., R. 2 E., entered blue till at 15 feet and continued in it to 130 feet. Another, 93 feet deep, in sec. 27 struck no blue till, penetrating sandy loam, 6 feet; fine gravel, 8 feet; yellow clay, 12 feet; gravel, 8 feet; quicksand, 56 feet; coarse waterbearing gravel, 3 feet.

OUTWASH.

The outwash connected with the Maxinkuckee moraine embraces not only material spread out along the outer border of the moraine, but also gravel and sand plains heading near the inner border and leading through the moraine, and perhaps also much of the undulating tract between the moraine and the Bremen moraine.

OUTWASH FROM OUTER BORDER.

Along the outer border of the Maxinkuckee moraine from South Bend southward to Yellow River valley a gravelly plain has apparently been overspread to some extent with the outwash from the moraine. The part near the Kankakee in St. Joseph County was probably also affected by the Lake Michigan lobe during the

development of the Kalamazoo morainic system. (See p. 175.) Gravel lies along and near the edge of the moraine but gives place to sand westward toward Kankakee River, scarcely a pebble being visible. As a rule wells in the gravel plain do not strike till, though many of them are 20 to 30 feet deep. One well 2½ miles south of Walkerton is reported to have passed through about 50 feet of pebbleless blue clay and terminated in fine sand under the clay at a depth of 80 feet.

At Yellow River the gravel plain extends back into the moraine nearly to the bend of the river south of Plymouth. It occupies nearly all the space between Twin Lakes and the river, a breadth of about 2 miles. The surface is rather sandy and is drifted in places into dunes, but is underlain by coarser material at slight depth. The gravel plain also extends up small valleys on the outer slope of the moraine north of Yellow River.

On the south side of Yellow River a till plain lies between the Maxinkuckee moraine and the outlying moraine that runs past Bass Lake. Outside or west of this outlying moraine a sandy plain extends from Bass Lake to the Tippecanoe Valley at Monterey. Near Tippecanoe River there is some gravel. North of Monterey basins occur along the border of the gravel plain, which is here about 30 feet above Tippecanoe River.

A line of glacial drainage descends westward from the Maxinkuckee moraine just south of Culver station near the west shore of Lake Maxinkuckee to a tamarack swamp around Manitou Lake. Its surface is strewn with cobblestones and small bowlders and is indented by shallow basins. South of it a spur of the main moraine extends west nearly to the Starke County line in secs. 29, 30, 31, and 32, T. 32 N., R. 1 E. From Manitou Lake the water may have discharged either southward along the west edge of the morainic spur to the Tippecanoe Valley or may have continued westward through a gap in. the outlying moraine in secs. 23, 26, and 27, T. 32 N., R. 1 W., to strike the Tippecanoe near Ora. Sand ridges on the outer slope of the Maxinkuckee moraine at many points from Lake Maxinkuckee northward to Pine Creek valley in the northwest township of Marshall County seem to have been heaped up by wind, but their sand was probably first laid, down as an out wash from the ice sheet as it was melting away from the moraine.

Below Leiters Ford the north side of the Tippecanoe Valley is occupied by a plain 3 or 4 square miles in extent, which carries fine gravel at its surface. This plain seems to grade into the Maxinkuckee moraine at the north and east borders and was probably formed by direct outwash from that part of the ice border. It remains gravelly only to the outlet of Lake Maxinkuckee. West of that outlet for 2 or 3 miles fine sand lies along the north side of the river. Near Monterey the pitted gravel plain outside the small moraine leading past Bass Lake sets in.

From the character of the material in the Tippecanoe Valley it appears that in course of the retreat of the ice sheet from the outer to the inner edge of the morainic belt unusually vigorous outwash occurred in three places—one near Monterey, another near Leiters Ford, and a third above Rochester in the vicinity of Manitou Lake. The distribution of the plain, first on the left, then on the right bank of the river, was controlled by the altitude of the bordering districts, the country being lower on the left or south bank than on the north from Rochester down to Leiters Ford and opposite conditions obtaining below Leiters Ford.

South of the Tippecanoe Valley, for a short distance south from Monterey, a gravelly outwash plain, already noted, with westward slope fills the space between the two morainic tracts. It pertains to the eastern tract, the western one having only sand along its outer or western border.

Farther south the weak western belt has sand on its outer border at numerous points and has a nearly continuous sand border from the Mill Creek[1] valley southward to Lake Cicott. In northeastern White and northwestern Cass counties the sand plain is several miles wide, but in southeastern Pulaski County it is less than 1 mile wide.

The outwash from the eastern and stronger undulating belt is not well defined except at the immediate border of the Tippecanoe Valley, though it forms some sandy deposits and ridges. The sand carries few pebbles, and the ridging may be referable to wind action. The deposits are probably to be classed as outwash from the ice sheet, though their precise mode of deposition remains uncertain.

Mill Creek, which cuts through this undulating belt, is bordered by a swampy flood plain one-half mile or more in width for 2 or 3 miles above the intersection and in the passage through it; on leaving the undulating belt the swampy condition ceases, but the valley continues broad throughout its course to the Tippecanoe. It seems to have been utilized as a line of discharge for glacial waters either direct from the ice sheet or from a lake held in front of the ice on the eastern slope of the undulating belt. The deposits along the valley are sandy and do not show the coarseness to be expected along a strong stream, indicating that the gradient was so low that only sand was transported down the valley.

[1]This Mill Creek, which enters the Tippecanoe below Winamac, should be distinguished from one that enters the same river near Rochester.

INTERMORAINIC DISTRICT.

In the Tippecanoe Valley an extensive sandy plain extends over central and northwestern Fulton County. From Monterey up to Leiters Ford the plain is on the north side of the river, but above Leiters Ford it is on the south side. The plain extends southeastward from Rochester up the valley of Mill Creek past Manitou Lake[1] and apparently heads in a reentrant angle of the receding ice sheet between the Erie and Saginaw lobes. At the head there is an undulating surface with basins and low swells, such as often characterize outwash aprons. Manitou Lake, now a single body of water with

an area of over a square mile, was formed by damming the outlet of a group of lakes that occupied several small basins in the plain. The sand plain has a definite south border in a sand ridge that runs from Mill Creek valley at Rochester westward to Mud Creek valley, descending about 30 feet (from 780 feet to 750 feet) in the 6 miles. On Mud Creek an extensive swamp, standing about 750 feet above sea level, is separated from the Tippecanoe by the sand plain, which seems to form a dam across the lower end of the Mud Creek valley. Probably for a considerable period the swamp was occupied by a lake, but the creek had cut its outlet sufficiently deep partly to drain it before the country was settled, and a system of ditches has since much reduced the swamp. The sand of the plain is rather light and drifts in places into dunes, of which the sand ridge along the south border is a conspicuous example. Wells, however, are reported to pass into fine gravel a few feet below the surface.

East of Kewanna, in secs. 24 and 25, T. 30 N., R. 1 E., and sec, 19, T. 30 N., R. 2 E., the plain between the undulating belt and the Mud Creek swamp is traversed by a network of sand ridges, which are 10 to 25 feet high and in places have the form of eskers. Gravel was found, however, on only one single high point at the western end of the system, and it remains to be determined whether the ridges are of esker-like origin or are simply due to wind. Indeed, the localization of the sand in this region is not as yet understood.

On Tippecanoe River below Warsaw a sandy plain that lies south of the stream appears more closely related to an ice border on that side than to the ridge that comes to Warsaw from the northwest. It may, however, consist of outwash from the reentrant angle at Warsaw, where the trend of the border changes from southeast to southwest.

BREMEN MORAINE AND INNER BORDER TILL PLAINS.

The Bremen moraine has its strongest development in the vicinity of Bremen, where it rises 20 to 25 feet above a marshy tract on the north and a gently undulating plain on the south. From Bremen to Hepton it forms a low basement ridge 10 to 15 feet high, bearing swells 10 to 20 feet in height. From Bremen westward to the Maxinkuckee moraine at Lakeville it is broken by many gaps, and where best developed its knolls reach scarcely 25 feet in height.

The ridge that sets in south of Hepton and runs southeastward to Warsaw has about the same strength as the ridge that leads to Hepton from Bremen. It consists of a low basement ridge with a relief of 10 to 15 feet, along which knolls 10 to 20 feet high are common. At its southeast end in the bend of Tippecanoe River north of Warsaw it rises into a series of sharp gravel knolls 30 to 50 feet high.

A sandy plain filling the gap south of Hepton has the appearance of the head of a line of glacial drainage, and sandy land extends from there down South Fork of Yellow River to its junction with North Fork a few miles below Bremen. This sand may be outwash from the small ridge on which Bremen stands, but its identification is uncertain because the valley may have afforded a line of discharge for water from a moraine farther east whose gravel plain extends about to the head of Yellow River. The later discharge, however, seems likely to have covered only a swampy tract about a mile wide along the river, leaving to the south a slightly higher plain, on which the hamlet of Millwood now stands, as a remnant of filling by outwash from the moraine at Bremen. North Fork of Yellow River, which crosses the moraine at Bremen, does not carry so well denned a sand plain and seems to have been, at best a weak line of discharge. Yellow River has apparently a very low gradient from Bremen to Plymouth and this may account for the weakness of outwash. Sand ridges near the junction of the two forks suggest the former presence of a small lake, but to prove its existence will require further study.

[1]This Manitou Lake should he distinguished from the Manitou Lake west of Lake Maxinkuckee.

Two till plains of considerable extent lie between the Maxinkuckee and the Bremen moraines. One is north of Yellow River in St. Joseph and Elkhart and on the edges of Kosciusko and Marshall counties; the other is southeast of Tippecanoe River in Kosciusko, Fulton, and Cass counties. The plain north of Yellow River has a general elevation of about 850 feet with a range from about 820 to 880 feet or more. It is very smooth with scarcely a knoll worthy of note. The drift is in large part a clayey till, though small areas with sandy soil were noted, the most conspicuous being near the Bremen moraine. Bowlders are far less numerous on its surface than on the tract south of Yellow River or on the main Maxinkuckee moraine to the west. Many dug wells obtain water from sand beds between the yellow and blue tills at depths of only 10 to 20 feet, but drilled and bored wells are carried to depths of 60 to 100 feet and penetrate more or less blue till.

The till plain south of the Tippecanoe gradually rises toward the southeast, or away from the river, from 750 to 850 feet above sea level. The bowldery strip of southern Fulton and northern Cass counties runs through the middle with an altitude of about 800 feet throughout its length of 15 miles or more. The southeastern edge of the till plain, which is determined by the outer border of a prominent moraine of the Erie lobe, passes near the villages of Claypool, Akron, and Macy. From the meridian of Rochester southwestward to Lucerne this plain has scarcely any knolls or ridges, but east of this meridian it bears small knolls and has a wavy surface. Its clayey till, occupied by beech, maple, and elm forests, put it in striking contrast with the looser-textured drift and oak forests of the morainic tract to the southeast. Many wells find water at moderate depths in sand between till sheets, but a few have been sunk 60 to 80 feet or more. The deeper ones are largely through blue till. Bowlders are rather common over all this plain but are especially numerous along the belt that runs

from near Lucerne in Cass County northeastward across southern Fulton County to the two Mud lakes at the head of Mud Creek. This belt (p. 132) seems likely to mark the position of the ice border in a brief halt in its retreat to the line of the large moraine southeast of it. The bowlders outside this belt seem to be no more abundant than is natural to a rapidly receding ice border.

NEW PARIS MORAINE.

COURSE AND DISTRIBUTION.

The next-younger well-defined moraine of the Saginaw lobe is named from New Paris, a village in southern Elkhart County, that stands near one of its most prominent points. The moraine, as here interpreted, includes a somewhat loosely assembled series of undulating and knolly tracts that covers the northeastern part of Kosciusko County and leads northward through central Elkhart County to the St. Joseph Valley immediately southeast of the city of Elkhart. It embraces a strip 6 or 8 miles wide, only part of which can be said to have morainic topography. Its western edge in Elkhart County and its eastern edge in Kosciusko County are especially difficult to define. In eastern Kosciusko and southwestern Noble counties it connects with a strong moraine of the Huron-Erie lobe that crosses it nearly at right angles and runs southwest to Logansport. Its connections at the north are obscured by a sand plain that borders St. Joseph River, interposing a wide gap, north of which a later moraine occupies the district.

In northeastern Kosciusko County two somewhat distinct ridges are present. The outer one, which is only 7 or 8 miles long and scarcely 1 mile wide, leads northwestward from the moraine of the Huron-Erie lobe along the north side of the Barbee Lakes and Tippecanoe Lake across T. 33 N., R. 7 E., to Dewart Lake in the southeastern part of T. 34 N., R. 6 E.; it is separated from the inner ridge by a nearly plain tract 1 to 2 miles wide. The inner ridge parts from the moraine of the Huron-Erie lobe in southern Noble County at High Lake, in the western part of T. 33 N., R. 9 E., and bears west-northwest across the north part of T. 33 N., R 8 E., entering Kosciusko County near Boydstown Lake, in the northeast part of T. 33 N., R. 7 E. Thence it bears northwestward across T. 34 N., Rs. 7 and 6 E., to Milford Junction, its inner border passing about a mile southwest of Turkey Lake, the largest lake in Indiana. In this distance of 20 miles or more from High Lake to Milford Junction it maintains a width of about 2 miles. North from Milford Junction, between Turkey Creek and Elkhart River, it is very strong, and west of Turkey Creek it is apparently continued by a gently undulating tract, which extends to the divide between Turkey and Little Bango creeks and which is in striking contrast with a very flat tract west of it. It continues northward with somewhat stronger expression along the west side of Elkhart River valley past Goshen to Yellow Creek, about 5 miles southeast of Elkhart. This brings it to the edge of the gravel plain of St. Joseph River, beyond which it has not been recognized.

TOPOGRAPHY.

Throughout much of its course this moraine rises only slightly above the outer border districts, a relief of 50 feet being rare. It has low swells with gentle slopes, a common height being 20 feet, though more fall below than exceed that height. Some knolls north of Boydstown Lake are 30 to 40 feet high and have steep slopes. “Waybright hill,” a conspicuous irregular-shaped mass of drift about 2½ miles south of New Paris, is by far the most prominent feature of the moraine; it reaches an altitude (barometric) of 1,025 feet, or about 215 feet above New Paris station, and is spread over the south half of sec. 22 and much of sec. 27, T 35 N., R. 6 E. The remainder of the moraine in Elkhart County, except perhaps a few knolls 3 to 4 miles southwest of Goshen, is below the 900-foot contour, and the part in Kosciusko County reaches 900 feet only at the extreme eastern edge of the county. The portion in Noble County rises a little above 900 feet, with a few points near High Lake that approach 1,000 feet.

The portion of this moraine in Noble and Kosciusko counties has numerous lakes along its course and on its borders, but that in Elkhart County has only one lake of sufficient size to be represented on the county map. This forms the head of Yellow Creek and is located in sec. 34, T. 36 N., R. 5 E. The principal lakes are as follows:[1]

Lakes along or near New Paris moraine.

Name.	Location.			Area in acres.	Depth in feet.
	T. N.	R. E.	Secs.		
Turkey	34	7	4, 5, 8–11, 14–17, 22–26	[a]5,66	68
Dewart	34	7	25	300	60
	34	6	30		
Milford	34	6	21–22	175	52
Tippecanoe	33	6	1, 11, 12	[a] 1,61	[b] 121
	33	7	6–9, 16–18		
Boydstown	33	7	10–15	[a] 1,057	43
Barbee Lakes[c]	33	7	20, 21, 26–29	(?)	19–42
Ridinger	32	7	1	300	45
	33	7	36		
Little Eagle	33	6	24–26, 35	700±	(?)
High	33	8	13	300	.....
	33	9	18	250	[d] 36
Bear	33	9	7, 8, 17, 18	120	.....
				320	[e] 57

[a] Square miles.
[b] The deepest lake depth reported in Indiana.
[c] A group of six small lakes.
[d] Lake lowered by ditching and depth reduced to 22 feet.
[e] Area and depth estimated by Prof. C. R. Dryer.

High Lake, as noted by Dryer in a special paper,[2] is nearly surrounded by sharp ridges of esker type distributed over an area of about 2 square miles. The most prominent ridge follows the south side of the lake and reaches a height of about 85 feet above it; in its highest part it incloses a kettle or basin which is at lake level. East and west of the lake basin are sandy and gravelly ridges 10 to 40 feet high. A short distance north of the lake a till ridge rises 50 to 60 feet above the lake and 30 to 40 feet above the general level of the country.

[1]The areas and depths are from Blatchley, W. S., and Ashley, G. H., Twenty-fifth Ann. Rept. Dept. Geology and Nat. Res. Indiana, 1900, pp. 31-32, in which maps are presented showing the contours of the beds of several lakes.

[2]Jour. Geology, vol. 9, 1901, pp. 123-129, with sketch contour maps.

Five miles northwest of High Lake along the valley of Turkey Creek another system of esker-like ridges, noted and mapped by Dryer,[1] inclose the basin of a lake about

50 acres in extent, known as Gordys Lake. The main ridge is 15 to 30 feet high and connects at the north with a plexus of ridges and mounds of corresponding heights. The lake has a maximum depth of 35 feet. Dryer suggested the term "esker lakes" for lakes of this class, whose existence and outline depend so largely on the presence of eskers.[2]

STRUCTURE OF THE DRIFT.

In Noble County the moraine bears gravel knolls and short esker-like ridges as well as knolls and ridges of loose-textured till. In Kosciusko County it has fewer gravel knolls (though these are common near Boydstown Lake) and a more clayey till. In Elkhart County it has a conspicuous gravel accumulation in the massive knoll south of New Paris, but elsewhere is mainly till so far as exposed.

The most conspicuous gravel knolls in the tract west of Elkhart River and the ones drawn upon for ballast for miles around are near the corners of secs. 26, 27, 34, and 35 and along the line of secs. 21 and 22, T. 36 N., R. 5 E. Much of the moraine in Elkhart and Kosciusko counties is a clayey till which was once timbered with beech and maple.

Bowlders, mainly granite, are numerous all along the moraine and especially on the sharp knolls and ridges. A few of red jasper conglomerate were noted.

Few records of wells sufficiently deep to show the structure of the lower part of the drift were obtained. As a rule wells strike a water-bearing sand or gravel under a thin sheet of till, their depth being 20 to 30 feet.

Records of a few deep wells at farmhouses in the undulating tract west of Turkey Creek were obtained. The well of Solomon Pebble, in sec. 3, T. 35 N., R. 5 E., on ground about 875 feet above sea level, is 230 feet deep, and terminates in sand and gravel under a thick bed of till. The well of Noah Bare, in sec. 15, T. 35 N., R. 5 E., on ground about 860 feet above sea level, is 148 feet deep; it passes through yellow till, 10 feet; blue till, 100 feet; yellow till, 30 feet; gravel, 8 feet, bearing water having a head 60 feet below the surface. A neighboring well in sec. 16 is 175 feet deep. The well of James Brown, in sec. 36, T. 35 N., R. 5 E., on ground about 840 feet above sea level, is 106 feet deep; it passes through surface till for 40 feet, and is thence in sand and gravel to the bottom. Neighboring wells in sec. 30, T. 35 N., R. 6 E., are nearly 100 feet deep and are largely in blue till. The well of Charles Michael, in sec. 25, T. 36 N., R. 5 E., on ground about 880 feet above sea level, is 157 feet deep, largely through till; near the bottom it struck water that has a head 50 feet below the surface.

OUTWASH.

Along the outer or southwest face of the moraine from the Barbee Lakes and west end of Tippecanoe Lake to Milford is a gravel plain apparently formed as an outwash from the moraine. When first settled it was largely prairie, the part from Leesburg northward being known as Turkey Prairie and that near the west end of Tippecanoe Lake as Bone Prairie. A gravelly and sandy tract between the Barbee Lakes and Boydstown Lake in eastern Kosciusko County has a northwestward slope that seems to indicate derivation from the moraine of the Huron-Erie lobe which lies southeast of this tract, rather than from the moraine of the Saginaw lobe north of it.

[1]Log. cit.

[2]Dryer also suggests that the plexus of ridges north of Gordys Lake forms an esker delta. In the present writer's opinion it is quite as likely to form the head of the esker, as eskers leading away from such a plexus are common. In this particular case also drainage is more likely to have been southward toward the ice margin than northward into the ice sheet.

A gravelly plain follows the Turkey Creek valley from Milford down to Elkhart River along the western or outer border of the main moraine. It continues down Elkhart River to the St. Joseph, but in this portion, being inside the moraine, it can scarcely be regarded as the outwash from it. As indicated below, this gravel plain of Elkhart heads in later moraines in Noble County. The plain bordering Turkey Creek slopes from the New Paris moraine toward the creek as if formed as an outwash from it. The discharge from the portion of the ice border in Kosciusko County is likely to have been westward through Yellow River, but that from the portion farther north may have found escape along the Elkhart Valley under the edge of the small portion of the ice sheet that extended across that valley while the moraine was forming. No outwash was detected along the western edge of the undulating tract that lies west of Turkey Creek and Elkhart River, the country consisting of a flat till tract with fewer bowlders than the undulating tract.

INNER BORDER.

The district northeast of the New Paris moraine is exceptionally varied, comprising both flat and undulating till tracts, smooth and pitted gravel plains, lakes both in till tracts and gravel plains, glacial drainage channels, and bowlder belts, all in close association.

The most conspicuous till plain lies around and southeast of Turkey Lake in northeastern Kosciusko and western Noble counties. On the west and south it is bordered by morainic tracts and on the north by a sandy plain.

This sandy plain covers the northwestern part of Sparta Township (T. 34 N., R. 8 E.) and the southwestern part of Perry Township (T. 35 N., R. 8 E.) in Noble County and extends westward across the northeast corner of Kosciusko County and the southeast part of Elkhart County to the New Paris moraine. Near Ligonier it extends on the north to the bluff of Elkhart River, but farther west is cut off from the river by a narrow bowlder-strewn gently undulating till tract. The plain has its coarsest material at the northeastern edge and slopes southwestward or directly away from the river bluffs

toward Solomon Creek, a small stream that heads in western Noble County and flows northwestward to Elkhart River through a channel whose depth is only 10 to 20 feet, though its width is about a mile. The portion of this shallow channel in Sparta Township, Noble County, is indented with basins containing swamps or small lakes. The distribution and character of the material as well as the slope of the sand plain indicate that it was built up as an outwash from the ice sheet at a temporary halt in the Saginaw lobe when it had receded about to the valley of Elkhart River in southeastern Elkhart and northwestern Noble counties. The Huron-Erie lobe probably stood at the eastern edge of the plain, and it is thought that the water from this lobe rather than that from the Saginaw cut the shallow channel along Solomon Creek. The junction of the two lobes at that time was probably near Ligonier. The Saginaw lobe, where not combined with the Huron-Erie lobe, appears to have developed no definite moraine on the border of the plain, but the Huron-Erie lobe has a strong moraine. (See p. 159.)

North of Elkhart River a gently undulating till tract several miles in width occupies the interval between the river valley and the next later moraine, the Middlebury. This till tract is traversed by a line of glacial drainage about a mile wide that leaves the Elkhart Valley about 2 miles east of Goshen and runs northward to Pine Creek and thence northwestward to the St. Joseph Valley east of Elkhart. Between this line of glacial drainage, which is known as the Canal Marsh, and the Elkhart Valley (which also was utilized as a line of glacial drainage) a tract of till with an area of about 16 square miles stands 30 to 50 feet above the bordering channels. The till is largely loose textured and bears on its surface many bowlders. The portion east of the meridian of Goshen has low swells and numerous basins, some of which are about 40 feet deep and are occupied by lakes. The portion northwest of Goshen has a relatively smooth surface with few basins.

East of the Canal Marsh channel the surface is gently undulating with swells 10 to 20 feet high and with very few basins. The altitude is generally about 900 feet or a little less, but in a group of knolls 6 miles east of Goshen it reaches 950 feet. The drift is somewhat more clayey than in the tract north of Goshen, but is on the whole a rather loose textured till. Bowlders are numerous over much of the surface and are especially abundant in a strip setting in about 5 miles east of Goshen and running eastward to the county line.

MIDDLEBURY MORAINE.

DISTRIBUTION AND CORRELATION.

A very prominent moraine in northeastern Elkhart County, Ind., is named from the village of Middlebury, by which it passes. It follows the south side of the Little Elkhart valley from western Lagrange County northwestward to the edge of the St. Joseph River valley, thence swings down the south side of the valley and dies out at the edge of the Canal Marsh channel, about 6 miles east of Elkhart. Its width along the St. Joseph is about 2½ miles, but along the Little Elkhart is scarcely 1 mile. It continues in faint form southward into the western edge of the southwestern township of Lagrange County, but dies out before reaching the Wabash Railroad.

With this moraine should probably be included a narrow morainic strip that follows the north side of Little Elkhart River from a point opposite Middlebury southeastward for about 6 miles, crosses to the south side of the river, and continues southeastward for 4 miles farther to the edge of a gravel plain known as the “Haw patch.” Its course is nearly parallel with and only 1 to 1½ miles distant from the inner border of the Middlebury moraine.

At the southeast side of the “Haw patch” gravel plain is a moraine that in all probability was occupied by the Huron-Erie lobe during the development of the Middlebury moraine by the Saginaw lobe and the Lagrange moraine, discussed below.

The correlations to the north of St. Joseph River are somewhat uncertain. There is a strong moraine on the north side of the valley in the southern part of Cass County, Mich., but it is doubtful if it can be correlated with the Middlebury moraine so well as with a later moraine, the Lagrange, with which it is more nearly in line. It is possible the Lake Michigan lobe covered the St. Joseph Valley and the north end of the Middlebury moraine for a few miles east of Elkhart. Between the western end of the Middlebury moraine and the moraine north of the river in Cass County, Mich., is a gravel plain in which basins are conspicuous. Such plains are characteristic of an ice border, and this one apparently supports the view that the ice receded across the valley from the Middlebury moraine to the moraine in Cass County, Mich.

TOPOGRAPHY.

The Middlebury moraine stands above 900 feet except on the lower slopes toward St. Joseph River, where it drops down to little more than 800 feet. A prominent point about 2 miles north-west of Middlebury in the southern edge of York Township rises slightly above 1,000 feet, and the geodetic station 2 miles south of Bristol reaches 970 feet. The outer edge of the moraine comes down to about 900 feet throughout its course in Elkhart County and along the western edge of Lagrange County. The relief above the outer border district ranges from 10 or 15 up to 120 feet.

The small parallel eastern ridge is lower than the main moraine, its altitude being generally a lit lie below 900 feet. It rises 20 to 50 feet above the valley of Little Elkhart River and about as much above a swamp that separates its southeastern end from the main moraine.

The portion bordering the St. Joseph Valley has a sharp knob and basin topography with numerous knolls 30 to

50 feet high and a few 75 to 100 feet. Basins and small lakes are inclosed among the knolls. The moraine is much less prominent from Middlebury southeastward, knolls being generally but 10 to 20 feet high and basins comparatively scarce. Basins in this part of the moraine are shallow and found chiefly along the outer border. The small inner ridge is characterized by knolls 10 to 25 feet high, some with steep but the majority with gentle slopes. Basins are not so conspicuous as in the main moraine.

STRUCTURE OF THE DRIFT.

The main moraine throughout its length, both in strong and weak portions, is composed largely of gravel or of very stony till. In places hundreds of large bowlders and thousands of cobblestones to the acre strew its surface. Scarcely any clayey till is present in Elkhart County, but it is not rare in Lagrange County, and it becomes still more common southeastward in Eden Township (T. 36 N., R. 8 E.).

OUTWASH.

A narrow strip of sandy and gravelly outwash appears along the outer border of the main moraine in the vicinity of Middlebury, and a tract of several square miles in the central and northern parts of Middlebury Township has so perfect an underground drainage that scarcely any surface drainage lines have been developed. In one place in section 8 drainage lines lead into a deep basin. There is also underground drainage in much of the "Haw patch" gravel plain at the southeastern end of the moraine. It is probable that the glacial drainage from the part of the moraine near Middlebury passed through a series of marshy channels leading westward from the central part of Middlebury Township to the Canal Marsh channel.

Between the main moraine and the inner ridge there is a swamp underlain with sand, through which a State ditch has been carried to improve the drainage. This swamp seems to have been a line of glacial drainage for water escaping from the Huron-Erie lobe after the Saginaw lobe had withdrawn from the weak moraine that lies east of it.

Little Elkhart River flows along the eastern edge of its valley and cuts in places into the weak moraine, indicating that the valley did not receive much outwash from the moraine, for otherwise the stream would have been thrown toward the west bluff. This valley, like the one drained by the State ditch, was probably utilized by later glacial drainage than that connected with the moraine which borders it. There is an extensive gravel plain outside of the Lagrange moraine in the headwater part of Little Elkhart River that opens into and in all probability discharged its waters down the Little Elkhart Valley. Some erosion seems to have occurred as a result of this glacial drainage, for the broad valley of the stream shows definite trenching, though its bluffs are low.

The features of the St. Joseph Valley opposite the end of the Middlebury moraine (p. 142) are such as characterize an ice border and it is probable that the St. Joseph was at one time the principal line of direct discharge from the Saginaw lobe, as well as the line of indirect discharge from tributary valleys. This might have been the case even if the Lake Michigan lobe overhung much of the plain along the river.

INNER BORDER.

Two narrow strips of till plain lie east of the inner ridge in the southwestern part of Lagrange County, one being north of Little Elkhart River and the other south. The one to the north has an area of about 12 square miles and is 2½ to 3 miles wide. It fills the space between the inner Middlebury moraine and the Lagrange moraine. Its till is rather loose textured, with some gravel and sand beds. The till strip to the south is scarcely 2 miles wide; it leads southeastward between the "Haw patch" gravel plain and the gravel plain on the headwaters of Little Elkhart River to a moraine of the Erie lobe in southern Lagrange County. It has a more clayey till than that in the strip north of the Little Elkhart.

The gravel plain which lies between these till plains, like the gravel plains to the north and south, are dependencies of the Lagrange moraine. (See p. 145.)

LAGRANGE MORAINE,

COURSE AND DISTRIBUTION.

The Lagrange moraine takes its name from the village of Lagrange, the county seat of Lagrange County, which stands at the junction of the Saginaw and the Huron-Erie lobes. From the village the Lagrange moraine leads northwestward, the correlative in the Huron-Erie lobe leads southwestward, and a short interlobate spur extends about 5 miles northeastward.

The Lagrange moraine runs west-northwestward from Lagrange about parallel with Pigeon River through southern Clay, northeastern Newberry, and southwestern Van Buren townships, Lagrange County, into the northeastern part of the northeast corner township of Elkhart County, where the St. Joseph River valley interrupts it for a few miles, though a pitted gravel plain fills much of the gap. It sets in again just north of the river in the southeast corner of Cass County, Mich., and continues west-northwestward for about 12 miles to the valley of Christian Creek, about 5 miles southeast of Cassopolis, west of which it disappears, giving place to an outwash apron from the Kalamazoo morainic system of the Lake Michigan lobe.

Southwest from Lagrange what appears to be the Huron-Erie equivalent of the Lagrange moraine is distinctly developed in the district between Lagrange and Elkhart River. It leads southwestward from Lagrange to Ligonier, passing just east of Topeka, and bears away

southeastward to Albion, where it merges with the great moraine of the Huron-Erie lobe. (See p. 158.)

The Lagrange moraine is about 3 miles wide, though somewhat broader at its northwestern end. The correlated moraine in the Huron-Erie lobe is 2 to 3 miles wide.

TOPOGRAPHY.

In its greater part the moraine rises above 900 feet and at a few points it exceeds 1,000 feet; much of it reaches between 900 and 950 feet. One elevation of about 1,000 feet is a knob in the northeast corner of Elkhart County, Ind., on the line of secs. 13 and 24, T. 38 N., R. 7 E.; another is the knoll bearing the Calvin geodetic station, in southern Cass County, Mich., whose altitude is 1,011 feet; a third is a ridge east of Lagrange in secs. 14, 15, 22, 23, 26, 27, T. 37 N., R. 10 E. In Indiana the relief above the outer border district is very slight, averaging scarcely 20 feet; above the inner border it is much greater, because of the Pigeon Valley depression. It is least near Lagrange, where it is fully 75 feet, increasing westward to more than 100 feet. In Michigan the relief above the outer border is only 25 to 50 feet except in a small district around the Calvin geodetic station, where it exceeds 100 feet. The relief on the inner border is somewhat less than it is on the outer.

The Indiana portion of the Lagrange moraine contains numerous small steep-sided knolls, among which are marshes and gently undulating till tracts. Several square miles in the northwest part of Lagrange County and the northeast part of Elkhart County have sharp knob and basin topography, in which knobs 40 to 60 feet high inclose tamarack swamps and small lakes without outlet. East of Lagrange a prominent ridge in secs. 10, 11, 14, 15, 22, 23, 26, and 27, T. 37 N., R. 10 E., stands 50 to 75 feet or more above a plain east of it and 25 to 50 feet above the bordering moraine on the west.

The portion in Michigan sets in near the State line with sharp knolls between Baldwins Lake and Long Lake. A fosse or depression, 20 to 30 feet below the gravel plain south of it and one-eighth to one-fourth mile wide, is present along much of the outer border from Long Lake to Christian Creek. The main ridge lies 1 to 2 miles or more back from the southern edge of the moraine, and diverges from it somewhat, trending slightly north of east across Calvin Township from sec. 30 to sec. 24, whereas the south border of the moraine trends south of east from sec. 31, Calvin Township, to Long Lake in sec. 9, Union Township. The district between the fosse and the main ridge is gently undulating and is thickly strewn with bowlders. The main ridge bears a chain of sharp gravelly knolls, which rise 50 feet or more above the general level; it is on one of these that the Calvin geodetic station was placed. North of the main ridge a chain of lakes leads from secs. 13 and 24 westward to Christian Creek. They are bordered closely by sharp knolls and ridges and have no broad outlets nor connecting strips of lowland. North of the chain of lakes in secs. 10, 11, 13, 14, 15, and 16, Calvin Township, is a gently undulating tract thickly strewn with bowlders which gives place farther north and west to a gravelly plain. The portion in Cass County, Mich., seems to have been formed in a reentrant between the Lake Michigan and Saginaw lobes. The strong ridge on which the Calvin geodetic station stood has the trend natural to the Lake Michigan lobe.

STRUCTURE OF THE DRIFT.

Most of the sharp knolls are composed of gravel even where the surface of the gently undulating moraine around them is clayey till. The knob and basin tracts are composed of gravel, cobblestones, and bowlders, with only a small amount of till or assorted material. Bowlders are conspicuous on the gently undulating as well as on the rough parts of the moraine in both Indiana and Michigan. Considerable sand and gravel seem to be associated with even the most clayey parts of the moraine, for strong wells are generally obtained at moderate depths.

Four records of waterworks wells at Lagrange, all within the area of a town lot, are presented by Dryer[1] to show the great differences in structure. He remarks that the majority of beds can not be correlated in any two of them. Dryer also calls attention to the occurrence of coal fragments in the drift of western Lagrange County (the part covered by the Saginaw lobe), but this is not surprising as the Saginaw lobe passed across the Michigan coal basin to reach Lagrange County, Ind.

The depth to rock is known at very few points in this region and where known indicates a large amount of drift. In Lagrange County several wells go down about 200 feet without reaching bedrock and but one well has been recorded as striking it. This was a farm well in the southwest part of the county outside the limits of the Lagrange moraine; the record was obtained by Dryer, who merely reports that “black slate” was struck at 150 feet.

A prospect boring for artesian water at the county jail in Lagrange reached a depth of 205 feet without entering rock or obtaining a flow. It possesses interest, however, from the reported occurrence, at a depth of 65 feet, of a soil bed which may mark the division line between the Wisconsin and the pre-Wisconsin drift. A well about 4 miles south of Lagrange on the farm of Dr. Drake is also reported to have penetrated a buried soil. The records of the borings are as follows:

Record of prospect boring at Lagrange jail.

	Feet.
Till, yellow	15
Till, blue, with thin beds of sand	50
Mold or soil, brown (Sangamon?)	4
Gravel, cemented	5
Gravel, loose, with water	8
Till, blue (Illinoian?)	45
Gravel, cemented	8
Sand and gravel, dry, or sandy till	70
	205

Record of Drake well near Lagrange.

	Feet.
Till, sandy, yellow	10
Till, blue	41
Gravel with inflammable gas	3
Clay, blue (till?)	46
Muck, black, with leaves and gas	6
Clay, soft, blue; no pebbles noted	24
Sand, water-bearing, coarse near bottom	10
	140

On the sharp ridge about 4 miles east of Lagrange a well 202 feet in depth, largely through till, struck no rock and failed to obtain water. On the same ridge another well

obtained water under a thick bed of till at 175 feet. Much of the ridge has a gravelly, cobbly surface; its north end is sandy.

On the Michigan part of the moraine many wells are sunk 75 feet or more before entering water-bearing sand or gravel; some of them pass through considerable dry sand. The water table is naturally low on account of the height of the moraine and the loose texture of the drift.

OUTWASH.

A gravelly and sandy outwash plain extends along the entire outer border of the Lagrange moraine except for about 3 miles in western Clay and eastern Newberry townships, Lagrange County, 5 to 8 miles west of Lagrange, where it gives place to a till plain.

An outwash apron in the reentrant angle between the Saginaw and Huron-Erie lobes southwest of Lagrange appears to have been built principally from the Huron-Erie lobe, for its gravel is much coarser on the side of the Huron-Erie lobe than it is on the side of the Saginaw lobe. Moreover, the slope away from the Huron-Erie lobe is the more rapid. The Saginaw lobe appears to have simply held its ground north of the gravel plain while the Huron-Erie lobe built up a large outwash apron. Gravel overspreads the southern tier of sections in Clay Township (T. 37 N., R. 9 E.) and about 12 square miles in the northwestern part of Clear Spring Township (T. 36 N., R. 9 E.), and a strip of gravel 1½ to 2½ miles wide leads westward from these townships down Little Elkhart River. On the north edge next to the Saginaw lobe there are marshy bowlder-strewn depressions, which were probably occupied by the ice while the outwash plain was receiving its coating of gravel.

[1]Eighteenth Ann. Rept. Indiana Dept. Geology and Nat. Res., 1893, pp. 80-81.

In northern Newberry Township and westward to the St. Joseph Valley an outwash plain of sandy gravel about 2 miles wide borders the Lagrange moraine. The western portion in the vicinity of St. Joseph River is somewhat cobbly. It contains several lakes among which Shipshewanna, Mud, Cass, East, and Hunters lakes are sufficiently large to receive names; the largest is Shipshewanna Lake with an area of about 200 acres and a depth of only 8 to 14 feet. In northeastern Elkhart County, between Hunters Lake and the St. Joseph Valley, the plain is trenched by ravines, some of which have been cut down 25 or 30 feet to the underlying till. This part of the plain has an altitude of about 875 feet. It stands nearly 50 feet above a lower plain on the Little Elkhart that leads in from the gravel plain in the reentrant angle southwest of Lagrange. This indicates that the Huron-Erie lobe was furnishing a strong line of drainage down to a time later than that of the most vigorous outwash from the Saginaw lobe.

On the outer border of the part of this moraine in Cass County, Mich., a gravel plain, indented with small basins and evidently built as an outwash from the ice, slopes rapidly southward toward the St. Joseph Valley, dropping from fully 850 feet at its northern edge to below 800 feet within 5 miles south. The conspicuous fosse (p. 144) that lies along its north edge for several miles east from Christian Creek seems to have been occupied by the ice sheet while the outwash plain was forming. Along the south border of the fosse the material is very coarse, with stones several inches in diameter mixed with the gravel, but it changes rapidly to finer material southward. Gravel is found, however, clear down to St. Joseph River opposite Bristol and thence westward about to a group of lakes in the northeast part of T. 38 N., R. 5 E. Farther west and south there is sand. The lakes, some of which are 200 acres or more in extent, are so shallow that cattle can wade all over them.

INNER BORDER.

There is but little space between the Lagrange moraine and the gravel plain of Pigeon River in Lagrange County, and that little is filled in part with sandy deposits and in part with a gently undulating loose-textured till interrupted by many marshy tracts that extend back from the river. The topography was probably developed in the course of the northward recession of the ice border. In Elkhart County the moraine is bordered on the north by the great gravel plain of St. Joseph River. In Cass County, Mich., a gently undulating plain of rather compact clayey till on the northeast border covers much of T. 7 S., R. 13 W. Numerous small lakes occur in this till tract. On the north and east the till gives place to sandy drift, probably connected with the next later moraine, the Sturgis.

STURGIS MORAINE.

COURSE AND DISTRIBUTION.

The Sturgis, a prominent moraine of the Saginaw lobe and of the reentrant between the Saginaw and Lake Michigan lobes, is named from the village of Sturgis, which stands at its outer edge in southeastern St. Joseph County, Mich. It lies chiefly in southern Michigan but enters Indiana slightly and connects with a morainic belt of corresponding age formed by the Huron-Erie lobe. It is greatly interrupted by lines of glacial drainage which head in later moraines and cut through it, producing gaps 1 to 6 miles in width.

West of Three Rivers, Mich., the Sturgis moraine runs into a great interlobate tract, which covers much of Fabius and Flowerfield townships, St. Joseph County, and of Newburg and southeastern Marcellus townships, Cass County, and which terminates on the south near the Michigan Central Railroad from Vandalia to Three Rivers. The greater part of this tract is shown by the distribution of outwash aprons to have been formed by the Lake Michigan lobe. However, part of it is occupied by a moraine of the Saginaw lobe running southeast from Corey Lake near Fabius to St. Joseph River. Its inner border is at Pleasant Lake in secs. 3 and 10,

Fabius Township. An outwash north of Pleasant Lake in secs. 3 and 10, Fabius, and sec. 34, Flowerfield, connects with a strong moraine of the Lake Michigan lobe lying west of it.

The great gravel plain that leads down St. Joseph River passes through this moraine in a gap 5 or 6 miles wide. East of this gravel plain and immediately south of Centerville the main ridge of the Sturgis moraine sets in and bears southeastward into Indiana, passing between Sturgis and Burr Oak, Mich., and just north of Lexington and Orland, Ind. In St. Joseph County, Mich., it has a width of 3 to 6 miles, but in Branch County, Mich., and in Lagrange County, Ind., it is somewhat narrower and is more or less separable into distinct ridges with intervening gravel plains. It connects with a strong moraine of the Huron-Erie lobe about 2 miles east of Orland in the north part of the northwest corner township of Steuben County, Ind. Outside of it, a weaker moraine of the Huron-Erie lobe connects with the Sturgis moraine about 2 miles west of the Steuben-Lagrange county line.

More or less isolated tracts on the inner border of the main moraine seem to be properly included with the Sturgis moraine. One tract about 5 square miles lies north of Centerville and is surrounded by the gravel plain of St. Joseph River. Another tract about 8 square miles, also surrounded by the same gravel plain, lies along the Michigan Central Railroad from Wasepi to Fairfax. A small sharply morainic tract north of Mendon on the north side of the gravel plain of St. Joseph River and other sharply morainic tracts east and south of Colon on the south side of the river seem also to belong to this moraine. Indeed, the country northeastward from the main part of the Sturgis moraine constitutes a transition belt several miles wide, in which a change from sharply morainic to nearly plane topography occurs. Northeastern St. Joseph and southeastern Kalamazoo counties embrace such a district on the north side of St. Joseph River, and western Branch County carries its continuation on the south side.

If all these isolated morainic tracts and the transition belt are thrown in with the Sturgis moraine it has a width of nearly 20 miles. Its outer border is very definitely determined by a great outwash plain that fits about it all the way from St. Joseph River to the junction with the morainic belt of the Huron-Erie lobes, and shows the trend of the ice border. The inner border, with its transition belt and long spurs reaching back into the bordering till plain, makes a striking contrast to the very regular outer border. The glacial map (Pl. VII) makes clear the position and relations of the various parts of the moraine and shows its relation to the moraines of the Lake Michigan and the Huron-Erie lobes.

TOPOGRAPHY.

ALTITUDE.

The altitude of the greater part of the Sturgis moraine is between 900 and 1,000 feet and is nowhere much below 900 feet. In several places it rises above 1,000 feet and in one place it appears, by barometric determination, slightly to exceed 1,100 feet. The altitude of this apparent highest point, which is in the Lake Michigan part of the interlobate tract in the central part of Newberg Township, Cass County, was determined by W. F. Cooper to be 1,115 feet. The altitude of another knoll a mile west is 1,070 feet. These knolls rise more than 100 feet above the surrounding country, there being probably less than 2 square miles in Newberg Township above the 1,000-foot contour. A single knoll in southern Flowerfleld Township, St. Joseph County, also on the Lake Michigan part, was found by Cooper to rise above 1,000 feet. A small area around the Sherman geodetic station, 4 miles northwest of Sturgis, rises above 1,000 feet, the hill on which the station stood being 1,038 feet. The altitude of the southeastern end of the main part of the moraine in northeastern Lagrange and northeastern Steuben counties, Ind., and of a part of its outwash apron slightly exceeds 1,000 feet. The lowest part of the moraine is on the borders of the St. Joseph Valley in central and eastern St. Joseph County, and this is not less than 850 feet, except perhaps in basins and sags among the knolls.

The outer border plain or outwash apron, where not trenched by later glacial drainage, stands nearly as high as the moraine. Its greatest height, 1,000 to 1,010 feet, is in northeastern Lagrange County, Ind., and it shows a steady decline to the westward along the edge of the moraine, being 935 at Sturgis, 890 opposite Klinger Lake, and 820 feet near White Pigeon. Its height, in the portion west of St. Joseph River near Fabius, on the outwash from the Saginaw part of the interlobate tract, is about 900 feet; on the outwash apron east of the moraine of the Lake Michigan lobe in sec. 34, Flowerfield Township, St. Joseph County, it is also about 900 feet.

The general relief of the moraine above the outwash aprons in the district west of St. Joseph River is only 30 to 50 feet, though as above indicated the highest knolls are about 200 feet higher. In the district southeast of the St. Joseph the relief is not generally more than 30 feet, but the knolls near the Sherman geodetic station reach about 100 feet above the neighboring part of the outwash apron.

On part of the inner border of the main portion of the moraine the gravel plain is somewhat lower than it is on the outer border which sweeps around the island-like tracts of moraine above noted. Its altitude near Centerville is 820 to 830 feet, but it rises southeastward to about 875 feet near Burr Oak. The adjacent parts of the moraine are 75 to 100 feet higher than the plain. The island-like tracts rise 25 to 100 feet above the plain, the most prominent being “Colon Mountain” just south of Fairfax station, which rises fully 100 feet above the bordering plain, or about 950 feet above sea level. The narrow strips of gravel plain between the morainic ridges southeast from Sturgis are somewhat lower than the outwash apron outside and become lower and lower

from south to north. The inner slopes of these ridges consequently show more relief than the outer ones.

CHARACTER.

The topography of the main part of the moraine is largely of the knob and basin type, most of the knolls have steep slopes. The portion near Sturgis and westward to Centerville is so rough that many steep grades are necessary on the Grand Rapids & Indiana Railway and on the numerous wagon roads that cross it. The railroad profile shows altitudes ranging from 877 to 957 feet within the limits of the moraine; barometric readings along a north-south road from Centerville across the moraine, taken by Cooper, shows a range from 823 to 942 feet between the lowest basins and the highest ridges or knolls crossed by it; the main road east from Sturgis across the moraine shows a range from 895 up to 954 feet, the altitude of the edge of the outer border plain being 937 feet.

Numerous basins in the midst of the moraine from the meridian of Sherman westward to the gravel plain of St. Joseph River are much lower than the outwash apron south of the moraine. Klingers Lake and the chain of lakes east of it have a water surface 50 to 60 feet lower and beds in places fully 100 feet lower than the part of the outwash apron immediately south of them. The surface in this part of the moraine thus ranges from about 100 feet above (at the Sherman geodetic station) to 100 feet below the outwash apron.

Southeast from Sturgis the moraine shows less roughness of topography than it does northwest of that place, much of the surface between ridges being graded up with gravel and sand to a plain. The outer ridge is practically continuous for about 14 miles from Sturgis to a point within 2 miles of Orland and yet in places is less than one-fourth mile wide and scarcely anywhere is a mile wide. The ridges back of it are interrupted by many gaps and more than half its surface is occupied by sandy plains.

Most of the knolls north of the main ridge near Centerville and east of Wasepi are small, but a few are 50 feet high, and, as above noted, Colon Mountain stands 100 feet above the bordering plains.

The district north of Mendon is similar to the knolly tracts, except that it fades gradually into a till plain toward the northeast.

In western Branch County the inner part of the Sturgis moraine is characterized by strips of sharply undulating or ridged drift alternating with nearly plane strips, all trending northeast and southwest directly toward the main part of the moraine instead of parallel with it. Some of the ridges are continuous for 3 to 4 miles and are loosely connected end to end for 10 to 12 miles. They rise 20 to 40 feet and in places 60 feet above the bordering nearly plane tracts. One of the most prominent, located 2 miles west of Bronson, was used as a site for a geodetic station. It has an altitude of 998 feet above sea level and is bordered by a plain whose altitude is 910 feet on the south and about 920 feet on the north. It forms the southwestern terminus of a narrow ridge about 3 miles in length.

In addition to the ridges and till plains this district, in western Branch County, is traversed by gravel plains that also trend northeast and southwest or parallel with the ridges. One of these gravel plains heads about 4 miles east of Colon and gradually expands westward to enter the gravel plain of St. Joseph River at Colon. South of this and separated from it by a ridged belt scarcely a mile in width is a longer and larger gravel plain that heads east of Matteson Lake and includes the lake. A still larger gravel plain (2 to 4 miles wide) leading from Coldwater River southwestward to Prairie River may have received an outwash from the moraine of the Huron-Erie lobes on the east as well as from the receding Saginaw lobe.

It is probable that all these drainage lines as well as the great gravel plain on the St. Joseph extended headward with the retreat of the ice sheet. The smaller two seem to have ceased to be functional before the ice had withdrawn, and the larger two to have remained in operation. Whether the elongated ridges were formed by gradual extension from southwest to northeast with the recession of the ice is not so clear. Indeed, their method of development is not as yet understood.

In the southern part of Branch County the ridges and knolls are distributed more irregularly than they are in the western part and they inclose gravelly and sandy plains as well as till plains. They commonly rise 20 to 30 feet above the plains and are either isolated or in small groups.

West of Three Rivers, in the prominent interlobate part of the Sturgis moraine, much very rough land is interspersed with basins occupied by lakes and marshes. Spurs of moraine run out into the lake basins and sharp knolls appear in the midst of the basins. The high knobs in central Newberg and southern Flowerfield townships are among the most prominent in southern Michigan. A strip on the northwestern edge of the tract that includes these sharp knobs is more choppy than the remainder of the moraine, possibly owing to overriding by the Lake Michigan lobe after the melting of the Saginaw lobe. (See p. 152.)

STRUCTURE OF THE DRIFT.

CHARACTER.

The surface of the Sturgis moraine is almost everywhere thickly strewn with bowlders. This is true not only of the main part of the moraine but also of the isolated or island-like tracts and of the transition belts on the inner border. The bowlders number several thousand to the square mile and are of various sizes up to 10 or 12 feet or more in diameter. Their presence in such numbers intensifies the morainic expression even of a belt whose knob and basin topography is strongly morainic. The bowlders, which include numerous quartzites and some

quartzitic conglomerates apparently from the Huronian formations north of Georgian Bay, are chiefly of granite, as in moraines farther south and west.

The sharp knolls and ridges of the moraine also carry a large amount of surficial cobbly material, and the numerous shallow cuts and gravel pits indicate that considerable water action attended their deposition. The beds show many interruptions and changes of dip and more or less disturbance. The amount of clayey till is very small, at least in the upper part of the drift, and there appear to be many changes both horizontally and in vertical section from loose-textured till to assorted beds of gravel and sand and back again. Few wells go down more than 60 feet and most of them only 20 to 40 feet, so the knowledge of the deeper part of the drift is very meager.

In the transition belt, on the inner border of the moraine, till of clayey texture is the prevalent deposit both on the ridges and on the intervening till plains. Some of the sharpest ridges and knolls, however, contain assorted material either in pockets or in beds.

THICKNESS.

Depth to rock.—Rock has been struck in deep wells at White Pigeon and Constantine south of this moraine and may have been reached in the waterworks well at Three Rivers. At White Pigeon the distance to rock is at least 182 and possibly 240 feet, there being a record of sand under so-called shale at 212 to 240 feet from the surface that leads to the suspicion that the “shale” is hard till; there is 140 feet of sand and gravel before reaching any till. At Constantine the drift is 136 feet thick, and at Three Rivers it may not exceed 100 feet. The wells at all these places are on ground whose altitude is about 800 feet. The altitude of the rock surface is, therefore, only 700 feet at Three Rivers and is considerably less at the other two villages. If this low altitude is maintained beneath the high part of the Sturgis moraine, as seems probable, there is possibly about 400 feet of drift in and beneath the highest knolls. The deepest recorded boring on the high tract in Newberg Township, Cass County, is in sec. 21, where 199 feet was penetrated and no rock was struck. Several wells in this and neighboring sections are over 100 feet deep, and W. F. Cooper estimates the average depth of wells for the township to be 97 feet. The amount of drift in this region can be roughly estimated by comparing the map of, rock contours (Pl. II) with the surface contour lines of the topographic map (PI. I).

Well data.—At Sturgis the waterworks wells have been sunk 140 feet without reaching rock and are thought by the superintendent to have been largely through sand and gravel.

Wells on the borders of Klingers Lake have artesian head about 20 feet above lake level and many of them flow. They range in depth from 20 to 80 feet, passing through layers of hardpan or cemented gravel and perhaps some till.

In the transition belt in western Branch County most of the wells are 20 to 40 feet deep, though a few tubular wells reached depths of 75 to 100 feet, largely through clayey till. The deepest wells are on the ridges.

In southeastern Kalamazoo County on the undulating till tract near Fulton one boring reached a depth of 275 feet without striking rock or obtaining water. It is reported to have been entirely through a clayey till, which apparently forms a more continuous sheet than it does in the districts south of St. Joseph River.

OUTWASH.

The principal outwash connected with the Sturgis moraine lies on the outer border of the main part of the moraine, but, as already indicated, small outwash plains lie between the constituent ridges in St. Joseph and southwestern Branch counties, and outwash plains are also developed in the transition belt along the inner border.

Outside of the moraine a gravel plain about 6 miles in average width and in places 10 miles in width is traversed for its entire length by Pigeon River. It is doubtful, however, if the outwash from the Sturgis moraine was carried south of the river, the deposit on that side being more probably formed as the ice border receded down the slope from the Lagrange moraine to the river. A portion of the plain north of the river may also have been built up during the recession to the position held by the Sturgis moraine. This interpretation is supported by numerous basins far out in the gravel plain and by the presence of considerable coarse material at distances to which it could scarcely have been carried by direct discharge from the moraine.

The possibility of submarginal deposition of some of the gravel and sand should also be considered, for in places a coating of bowldery material has apparently been let down by the melting of the overhanging ice. Such material is especially noticeable in northeastern Lagrange County in a reentrant between the Saginaw and Huron-Erie lobes east of a line running from Lexington to Mongo.

Generally speaking, the coarsest material lies in a narrow strip along the front of the moraine, and within 2 miles from the edge it has given place to sand or very fine gravel. The descent of the plain appears to be more rapid directly away from the moraine southward than along the moraine westward, though it is rather rapid in the latter direction.

Wells, reported to be through sand and gravel, have penetrated the highest part of the gravel plain near Lexington and Mongo, Ind., to depths of 70 or 80 feet before reaching the water table. At White Pigeon, Mich., fine sandy gravel was found to a depth of 140 feet, and at Sturgis the waterworks wells appear to have been through gravel and sand to a depth of 140 feet. So far as can be learned all the material is loose or uncemented and seems likely to have been deposited in

the Wisconsin stage of glaciation and perhaps in large part immediately preceding and accompanying the development of the Sturgis moraine.

The topography along the south border of the Sturgis moraine is more diversified on the west side of the St. Joseph Valley than it is on the east side. In the vicinity of Fabius are characteristic outwash features in the form of a pitted gravel plain. South of this, in southern Fabius and northern Constantine townships, St. Joseph County, are sandy undulating tracts whose structure is what might be expected in an outwash apron, but whose surface is more rolling than in the ordinary outwash apron; they include knolls as well as basins, but show few bowlders or coarse pebbles. West of this for a few miles in the eastern edge of Cass County there is no definite outwash, the moraine being bordered by a gently undulating till tract. But in southwestern Newberg Township sandy drift sets in along the south border of the moraine and extends west past Vandalia to the gravel plain that borders the Kalamazoo morainic system of the Lake Michigan lobe. This sandy district, which includes several lakes and is much interrupted by basins and marshes, may have been produced during the retreat of the ice across it instead of as an outwash from the Sturgis moraine. The same is true of the undulating sandy tract in Constantine and Fabius townships. The outwash on the east side of the moraine of the Lake Michigan lobe in secs. 3 and 10, Fabius Township, and sec. 34, Flowerfield Township, seems to have been deposited among stagnant parts of the ice sheet, for it is interrupted by many basins.

The strips of gravel plain between the constituent ridges of the Sturgis moraine in southeastern St. Joseph and southwestern Branch counties have rapid variations from coarse to fine material, some portions being cobbly while others near by are sandy. On the whole, however, the sandiness increases from Branch County northwestward toward the St. Joseph Valley through southeastern St. Joseph County along the course of discharge of the glacial waters. The gravel plains that extend up into the transition belt in western Branch County have a moderately coarse gravel with perhaps less admixture of sand than the plain with which they connect in eastern St. Joseph County. At the eastern or headward ends, however, the material seems to have been somewhat irregularly and indefinitely assorted by stream action. In places it is difficult to determine where the gravel has its head, the passage from the till into the gravel being apparently gradual rather than abrupt.

INNER BORDER.

Attention has already been directed to the gradual change from moraine to till plain and to the extension of morainic spurs back into the till plain to the inner border of the Sturgis moraine (p. 147). In southeastern Kalamazoo and southwestern Calhoun counties an area of about 100 square miles is composed of clayey till and has a gently undulating surface, knolls 10 to 20 feet high being numerous. It is strewn with bowlders liberally but not so heavily as the bordering moraines. This till tract is limited by the Tekonsha moraine on the northeast, by the Sturgis moraine near Mendon on the southwest, by a gravel plain known as Climax Prairie (formed in connection with the Tekonsha moraine) on the north, and by the great gravel plain of the St. Joseph River valley on the south.

South of the St. Joseph plain, in northern and central Branch County, an undulating till tract similar to that north of the gravel plain is traversed by Coldwater River from Coldwater to Union City. West of the Coldwater the tract is interspersed with the till ridges and knolls of the transition belt already discussed (p. 147). East of the river the tract has a gently undulating surface with few noteworthy knolls.

The altitude declines markedly westward across the district, being 1,025 to 1,060 feet above sea level near the border of the Tekonsha moraine, about 980 feet at the bluff of Coldwater River, and about 920 feet on the meridian of Bronson (disregarding the knolls). The drift is largely clayey till with a very few gravelly knolls. Bowlders are everywhere numerous.

TEKONSHA MORAINE.

COURSE AND DISTRIBUTION.

The name Tekonsha is applied to a comparatively strong moraine of the Saginaw lobe which sets in at Quincy, Mich., runs northward rather weakly to the St. Joseph Valley, in which it occupies a great bend, and is thence strongly developed westward to the village of Tekonsha, Calhoun County. Here it crosses the St. Joseph Valley, leads northwestward across the southwestern part of Calhoun County, and comes to the Kalamazoo Valley near the line of Calhoun and Kalamazoo counties. It has a general width of 4 to 5 miles but is in places much narrower. As interpreted, the moraine finds continuation northward from the junction of the Saginaw and Lake Michigan lobes. This spur, however, is developed only from the river northward about 6 miles to the border of a later moraine of the Saginaw lobe that follows the north side of the Kalamazoo Valley.

The moraine is reduced to a remarkably narrow strip in its passage across the Nottawa Creek valley northwest of Burlington for 3 to 4 miles, being scarcely one-half mile wide. It is similarly reduced along the south bluff of St. Joseph River for 3 miles west from Tekonsha. In each place a gravel outwash apron fits about the southern edge of the moraine and by its contrast helps to give the hummocky, bowldery morainic strip strong expression despite its narrowness.

Correlative moraines of the Lake Michigan lobe and of the Huron-Erie lobe connect with the Tekonsha moraine at its northwestern and southeastern ends respectively.

The correlative moraine of the Lake Michigan lobe, which occupies a belt about 3 miles wide on the south side of the Kalamazoo Valley, is well developed for 7 or

8 miles southwest from its junction with the Tekonsha moraine, and is then cut off by a great gravel plain that heads in moraines north of Kalamazoo River and runs southward through central Kalamazoo County. Beyond this plain its continuation is doubtful, though a bowldery strip was traced from the end of the moraine as far as the north end of Long Lake or half way across the gap. The connection may be found in a sharply ridged tract that sets in near the south edge of the southwest township of Kalamazoo County about 3 miles southwest of Schoolcraft and runs southward to Rock River at Howardsville, beyond which to the vicinity of Vandalia it overrides or forms the western edge of the sharply morainic tract in eastern Cass and western St. Joseph counties. (See p. 149.)

The correlative moraine of the Huron-Erie lobe, which connects with the Tekonsha moraine near Quincy, Mich., is rather vaguely developed, but apparently embraces an undulatory belt that leads westward and southward to the State line just east of Orland, Ind. It may also include undulating tracts south of Quincy, in Quincy and Alagansee townships, Branch County, Mich. The portion south of the State line is so closely combined with other moraines of the Huron-Erie lobe that separate description can scarcely be given it and the entire system is considered together in another section. (See pp. 148-149.)

TOPOGRAPHY.

ALTITUDE AND RELIEF.

From Quincy to Tekonsha the altitude of the Tekonsha moraine drops from about 1,100 to 1,000 feet. Beyond Tekonsha a small area at the north bluff of the St. Joseph, 2 miles to the west, has an altitude of 1,075 feet, and another small area 2 to 4 miles to the northeast rises above 1,000 feet, but the greater part of the moraine south of Kalamazoo River is between 925 and 975 feet. North of the Kalamazoo the interlobate spur is not far from 900 feet in general elevation. It stands but little higher than the bordering gravel plain, and its sags and sloughs are lower than the gravel plain.

The general relief of the moraine above the outer border district is only 20 to 30 feet, though that of individual knolls or groups of knolls is 100 feet. The relief of the inner border between St. Joseph and Kalamazoo rivers is about the same as that of the outer, though a little greater near the Kalamazoo and a little less near the St. Joseph. For part of its course the crest of the moraine forms the divide between tributaries of the St. Joseph and those of the Kalamazoo.

CHARACTER.

On the whole the Tekonsha moraine has not so rough a surface as the Sturgis moraine. Many of its knolls are but 10 to 15 feet high and few exceed 40 feet. It is, however, exceptionally prominent in two places; one, in western Tekonsha Township, is locally known as “the Alps” and has knolls 80 to 100 feet high with very steep slopes; the other, in the reentrant on the south side of Kalamazoo River near the line of Kalamazoo and Calhoun counties, is known as “Tobys Hill” and rises more than 100 feet above neighboring districts on the east, north, and west.

In places peat bogs and basins are conspicuous. On the south side of St. Joseph River, immediately east of Tekonsha, 2 or 3 square miles is rendered largely waste land by the presence of boggy basins. Small knolls rise like islands from the boggy tract and a prominent part of the moraine sweeps around its eastern and southern edges. This prominent part of the moraine also includes boggy basins in the southwest part of Clarendon Township. Between Nottawa Creek valley and Kalamazoo River several small lakes are inclosed by morainic knolls, and others lie in gravel plains on the inner border of the moraine. Lakes are especially conspicuous from Quincy southwestward in the correlative moraine of the Huron-Erie lobe, Marble Lake and Coldwater Lake each having an area of more than 2 square miles, and several others having areas of one-fourth to three-fourths of a square mile. They are distributed in a chain which perhaps marks the line of a preglacial valley extending from near Quincy south-southwestward into Indiana.

The interlobate spur north of the Kalamazoo Valley is more conspicuous by reason of its depressions and basins than by its knolls and ridges. Some of the depressions are 30 to 50 feet below the bordering gravel plains; they seem to indicate that stagnant ice persisted here during the building of the gravel plains by outwash from a later moraine.

The correlative in the Lake Michigan lobe west of the reentrant angle in eastern Kalamazoo County has a very hummocky topography and incloses small lakes and basins. In roughness it is scarcely excelled by any part of the Tekonsha moraine unless it be “the Alps” west of Tekonsha.

GLACIAL DRAINAGE CHANNELS.

The moraine is interrupted by several valley-like gaps where glacial drainage seems to have been forced across it while the ice sheet was standing near its inner edge. The most conspicuous of these interruptions is a low gravel plain over 2 miles in average width immediately north of Tekonsha. South of the St. Joseph two narrow gaps only one-fourth to one-half mile wide cross the moraine east of Tekonsha in Clarendon Township. Between them is a narrow strip of moraine on which Clarendon Center stands. The channels unite near the Branch County line and the single valley continues southwestward emerging from the moraine about 2 miles northeast of Girard in secs. 11 and 12, T. 5 S., R. 6 W. A few miles farther south another channel leads across the moraine from St. Joseph River to Hog Creek, passing just north of the hamlet of South Butler. Between South Butler and Quincy a network of channels occupies more than half the surface, above which morainic knolls rise in small groups. A portion of the

glacial drainage seems to have discharged from Quincy westward past Coldwater, and a portion northwestward past Girard along the Hog Creek valley to Coldwater River. These channels follow lines where the moraine was especially weak and where passages could therefore be easily opened.

STRUCTURE OF THE DRIFT.

COMPOSITION.

The drift of the Tekonsha moraine is generally loose textured even where not assorted. The looseness naturally results from the presence of much sand derived from the underlying or neighboring sandstone formations, as well as from the action of water and the removal of finer material during deposition. The nearest approach to clayey till noted is in western Calhoun County, a few miles south and southwest of Battle Creek, where the moraine laps upon a clayey plain that extends into eastern Kalamazoo County. The principal tracts of beech and maple timber are found here. There is ordinarily much diversity of structure within even small areas. On a single farm one well may be largely in sand or gravel, another in a loose-textured till, and a third in a combination of the till with sand and gravel. The interlobate spur north of Kalamazoo River is largely sand and gravel.

BOWLDERS.

Bowlders are very numerous over nearly the whole surface of the moraine and are also embedded in the drift, for nearly every cutting observed is full of them. They are least conspicuous on the interlobate spur north of Kalamazoo River. The bowlders are such an encumbrance that piles of them appear in nearly every field and several miles of fences are built of them. Places near Hog Creek in northeastern Branch County were estimated to carry 1,000 bowlders to the acre and some knolls in that vicinity are literally covered with them. Many of the bowlders are large enough to be shaped into building stone. The smaller ones are useful for checking the gullying of hillside slopes when thrown into ditches and are thus easily buried. The majority of the bowlders are well rounded, probably by exfoliation, and few show striated surfaces. As in the moraines to the southwest, granite rocks greatly predominate, but quartzites and quartzitic conglomerates abound and numerous other rocks are represented. Local sandstone in mass is rare on the surface, though blocks as well as small pieces abound within the drift sheet.

THICKNESS.

Relation to table-land of sandstone of the Marshall formation.—Compared with the drift in the district outside or southwest of the moraine, the drift of the Tekonsha moraine is very thin. This is due to the position of the moraine, which stands on the edge of the table-land of sandstone of the Marshall formation, whose rock surface is much higher than that of the adjacent lowland underlain by the Coldwater shale. The sandstone table-land has an altitude of 900 feet or more in Calhoun and eastern Branch counties, and some of its highest points exceed 1,000 feet. Accordingly, in numerous places along the moraine rock is struck at 50 feet or less, and in the district north of Quincy it stands above the level of some of the sags or channels in the moraine. The table-land is interrupted more or less by deeply eroded preglacial valleys that lead into the lowland to the southwest and at such places the drift must be Very thick, presumably 200 feet or more, for much of the outlying lowland is at least 200 feet lower than the table-land. The table-land extends slightly into the eastern edge of Kalamazoo County south of the river near Climax but seems to be interrupted by a deep valley in the vicinity of the river. Borings in and near Augusta reach a level 100 feet below the present stream without encountering rock, one boring being 150 feet and another on higher ground 220 feet.

Well data.—The following record of one of the deep wells near Augusta was obtained from the driller. The well is on the Colchester farm on the northwestern outskirts of the village, at an altitude perhaps 120 feet above Kalamazoo River. Water rose within 70 feet of the surface.

Record of Colchester well near Augusta, Mich.

	Feet.
Gravelly or sandy material with thin beds or partings of clay	140
Clay, blue, rather compact (probably pre-Wisconsin)	80
Cement crust above water bed.	
	220

A well at the schoolhouse in Augusta on ground about 50 feet above Kalamazoo River was carried to a depth of 150 feet and passed through considerable blue till in its lower part. The till is struck beneath bordering gravel plains on the north side of Kalamazoo River and seems to be independent of and to antedate the moraine. Probably it is of pre-Wisconsin age.

The deepest well in the correlative moraine of the Lake Michigan lobe south of Kalamazoo River of which a record has been obtained is that of Mr. Schram, opposite Galesburg. It is on ground about 120 feet above the river and reached water at about 100 feet. The drift there is largely loose textured and gravelly.

A well on the Heritz farm east of Climax on ground about 975 feet above sea level is reported by the driller, S. Barlow, of Galesburg, to have struck sandstone at 47 feet and to have obtained a good supply of water at 50 feet. This seems to be near the western edge of the table-land of sandstone of the Marshall formation, for wells a mile west of the Heritz farm were sunk to a depth of 100 feet without reaching rock.

Records of two wells south of Tekonsha show a striking difference in drift structure as well as a large amount of drift. One at William Wagner's, on a sharp morainic knoll in sec. 3, Girard Township, is largely through till, part of it a stiff clay, and strikes rock at about 175 feet; its entire depth is 184 feet. Another on the outwash apron just outside the moraine, on the farm of J. W. Mitchell in sec. 33, Tekonsha Township, entered rock at 164 feet and reached a depth of 180 feet; it penetrated 45 feet of gravel, below which it was in quicksand to the rock.

Both wells are on ground nearly 1,000 feet above sea level. Along the moraine northwest from the wells a thin sheet of bowldery, loose-textured till covers a thick deposit of sand, which is entered in some wells at 15 to 20 feet.

On a prominent knoll in sec. 22, Butler Township, Branch County, about 70 feet above the surrounding country or 1,075 feet above sea level, a well 107 feet deep enters rock at 90 feet, after penetrating considerable till under a surface deposit of gravel.

OUTWASH.

Except for a few miles in southwestern Calhoun County, where it laps upon a till plain, the Tekonsha moraine is bordered by well-defined outwash aprons or by lines of glacial drainage. The correlative moraine of the Lake Michigan lobe in eastern Kalamazoo County also is bordered by an outwash apron, and correlative in the Huron-Erie lobe in southern Branch County is deeply indented by gravelly aprons that extend back into it; the latter has a continuous belt of gravel on its outer border.

REENTRANT ANGLE.

The outwash in the reentrant angle between the Saginaw and Lake Michigan lobes in eastern Kalamazoo County shows a marked slope from northeast to southwest along the edge of the Lake Michigan correlative. The altitudes and slopes are well shown in the profile of the Grand Trunk Railway, which traverses it from northeast to southwest. The altitude is 990 feet at the northeast edge of the gravel plain, 976 feet at Climax, and 912 feet at Scott station, 6 miles southwest of Climax, giving a slope southwestward of about 10 feet to a mile. Gravel and cobble are plentiful at the northeast, but sand becomes conspicuous toward the southwest near Scott. Basins containing small lakes appear at the northeast but become inconspicuous toward the southwest. Some irregularity of surface in the southwestern part seems likely to be the result of glacial drainage rather than the work of modern streams.

The till plain south of the outwash apron extends to the outer border of the Tekonsha moraine near East Leroy.

GRAVEL PLAIN OF ST. JOSEPH VALLEY.

From the vicinity of East Leroy southeastward to the St. Joseph Valley, a distance of 10 miles, lies the head of the great gravel plain that leads down the St. Joseph Valley. This plain is entered by Pine Creek and Nottawa Creek as well as by St. Joseph River. The part traversed by Pine Creek is near the western border and is more sandy than the more central part along Nottawa Creek. Between Pine and Nottawa creeks, in the vicinity of the hamlet of Abscota, the surface of the gravel plain is bowlder strewn for 1½ to 2 miles out from the moraine. Between Nottawa Lake and St. Joseph River, basins (one of which contains Turtle Lake, with an area of about one-half square mile) are conspicuous for 3 or 4 miles southwest from the moraine. The plain has a rapid southwestward slope, its altitude next to the moraine being about 975 feet, opposite Athens (8 or 10 miles southeast) 900 feet, and opposite Leonidas and Colon (8 miles farther) about 860 feet. Beyond the last-named place it descends perhaps 2 feet per mile down the St. Joseph Valley to the head of the Kankakee at South Bend, its altitude at that city being about 720 feet. The gravelly and cobbly part of the plain is chiefly in the rapidly sloping part above Colon, the remainder being a sand or sandy gravel.

In the St. Joseph plain are features that seem to indicate considerable filling or aggradation, and also some cutting down, for the borders of the gravel plain all the way up to the Tekonsha moraine are determined by distinct bluffs of till. The bluffs generally are only 15 to 30 feet above neighboring parts of the gravel plain after due allowance has been made for trenching of the gravel plain by modern streams. They are abrupt, as if cut down rapidly, and that, too, in a valley which from Burlington down to Colon is fully 6 miles in average width. Filling or aggradation is shown by the character of the deposits, which throughout the valley and to depths as far as the wells ordinarily penetrate (20 to 40 feet) are assorted water-laid material, strikingly different from the material of the bluffs.[1] The basins also suggest a filling of the bordering tracts, for they seem to be the result not of excavation by the glacial stream but of the melting of stagnant ice masses that persisted until the valley aggradation was completed. The most probable interpretation is that a very large valley, as broad as this gravel plain and considerably deeper than the depth of the gravel plain below the neighboring till tracts, was first excavated and afterward partly filled with the gravel and sand. It is a matter of observation that large streams like the Mississippi and Missouri rivers scour portions of their beds at flood seasons to depths approaching 100 feet, and then at ordinary river stage slowly fill the holes thus produced. The meanderings of current may in the course of time bring all parts of the valley under deep scouring action followed by partial filling, and thus give it the appearance of having once been more deeply excavated.

INTERMORAINIC GRAVEL PLAIN.

Immediately above Burlington, where St. Joseph River emerges from the Tekonsha moraine, the valley is a scant half mile in width and contrasts strikingly with the broad gravel plain 6 to 9 miles wide which the river enters immediately outside the moraine. Nevertheless, glacial drainage prevailed through this narrow part of the valley during the recession of the ice, for it served as the outlet from a gravel plain that lies within the moraine just north of Tekonsha. This latter plain covers about 12 square miles and stands a few feet lower than that outside the moraine, its altitude at Tekonsha station being 945 feet. To escape westward down the St. Joseph Valley it must have trenched the headward end of the large plain outside the moraine to a depth of 30 feet or more. This inner plain seems to have a slight slope southward from the inner part of the moraine at

Nonosseppe Lake to the St. Joseph Valley at Tekonsha. Its material is a rather fine gravel, in places sandy.

GRAVEL PLAIN OF HOG CREEK.

On the outer border of the moraine immediately south of St. Joseph River a space of a mile or more carries very little outwash. Beyond this space a gravel plain extends southward past Hog Creek to the Coldwater Valley at Hodunk. It embraces what is known as Girard Prairie and covers an area of about 15 square miles. The plain has an altitude of 990 to 1,000 feet next to the moraine but slopes down to about 950 feet at the Coldwater Valley by Hodunk, a descent of 50 feet in 5 or 6 miles. Bowlders are scattered over it for half a mile or more from the edge of the moraine, but are rare farther out. The material is a coarse gravel and cobble next to the moraine but becomes a finer gravel on passing out into the plain.

[1]A boring on the Fimple farm, in sec. 20, Sherwood Township, and another on the Greenfield farm, in sec. 4, Sherwood, are each on this gravel plain and are reported to have penetrated a great depth of blue clay, presumably till, under the gravel. In the Fimple boring the gravel is 30 feet thick and the underlying blue clay was penetrated to a depth of 214 feet from surface without reaching the bottom. The Greenfield well is reported to be similar. These notes were furnished by C. E. Swain, of Sherwood, Mich.

Basins are deep and numerous next to the moraine, one of them being occupied by a lake of perhaps 80 acres area. A mile or more from the moraine they are inconsiderable.

Numerous lines of glacial drainage in northeastern Branch County head in the moraine and lead down the Hog Creek valley across the southern edge of the gravel plain just discussed. These channels were in operation apparently until the ice border had receded into western Hillsdale County to the vicinity of Litchfield, for gravel plains west of Litchfield extend into marshy channels that lead to Hog Creek near South Butler. There appears also to have been northward drainage down Hog Creek from the vicinity of Quincy to these channels near South Butler and thence westward along the creek to the Coldwater at Hodunk. The Coldwater Valley not only served as a line of escape below Hodunk for glacial waters from the Hog Creek channels and the broad gravel plain, but also for drainage from the region now tributary to it in southeastern Branch County. One channel passes west from Quincy; another follows down the valley from a gravel plain that surrounds Coldwater Lake.

CHAPTER VIII. MORAINES OF THE NORTHERN LIMB OF THE HURON-ERIE LOBE IN INDIANA.

By FRANK LEVERETT.

COURSE AND DISTRIBUTION.

A broad and somewhat complex series of moraines lying along the north border of the Huron-Erie lobe in northeastern Indiana seem to be the equivalent of several moraines of the Saginaw lobe that connect with it on the north. The moraines lie entirely north of Wabash River, though for a few miles near Logansport they follow the north bluff closely.

They have their westernmost appearance on the north bluff of Wabash River a few miles above Delphi, Ind. Here they have a width of only 2 to 3 miles, but in passing northeastward across Cass County they widen to 10 miles and so continue throughout much of their course to the Indiana-Michigan line. Their width is much greater than 10 miles in the northern counties of Indiana, if the gravel plains lying between constituent ridges are included, and the combined width of the moraines proper in places exceeds 10 miles.

For a few miles west of Logansport the western or outer border of the moraines follows Crooked Creek, and the inner border lies along the Wabash bluffs, the width of the moraine here being about 3 miles. From the head of Crooked Creek the outer border leads northeastward to Warsaw, passing near the villages of Macy, Akron, and Claypool. The inner border follows up the Eel River valley to the western edge of Wabash County and then gradually bears away from the river to the north, passing about 2 miles west of Laketon, 4 miles northwest of North Manchester, 1 mile east of Sidney, and past Larwill to the head of Tippecanoe River, about 8 miles north of Columbia City. Thus far the deposits form a single massive moraine, but farther to the northeast they separate into two or more moraines, between which are gravel plains and nearly plain till tracts. From a point north of Columbia City northeastward into Michigan the inner border of the moraines is overlapped by the Mississinawa morainic system of the Huron-Erie lobe, and a little farther north it is joined on the east by the Salamonie moraine, also of the Huron-Erie lobe.

At Warsaw the outer border connects with the comparatively weak Bremen moraine of the Saginaw lobe, and between Warsaw and Claypool it connects by slight offshoots toward the northwest with the undulatory district on the inner border of the Maxinkuckee moraine. From Warsaw the outer border runs eastward past Little Eagle and the Barbee lakes to eastern Kosciusko and southwestern Noble counties where it connects with the New Paris moraine of the Saginaw lobe. (See p. 138.)

Farther east, at High Lake, about 8 miles southwest of Albion, an outer member 2 or 3 miles wide runs

northward past Ligonier and Topeka to Lagrange, where it connects with the Lagrange moraine of the Saginaw lobe. The main moraine, however, continues northeastward from High Lake through the central and northeast parts of Noble and southeast part of Lagrange into Steuben County, the outer border passing near Albion, Brimfleld, Rome City, and South Milford.

Between the main moraine and the outer member ridged and hummocky land is locally developed, but most of the surface is level or very gently undulating. One ridged belt runs out like a spur about 3 miles northwestward from Rome City. Other less conspicuous ridges with west-northwest east-southeast trend are found northwest of Wolcottville. An undulating strip runs northward from Wolcottville through the eastern part of T. 36 N., R. 10 E. A poorly developed moraine on the eastern edge of a high gravel plain in northeastern Lagrange County runs northeastward from Mongo to intersect with the Sturgis moraine at Wall Lake, 2 or 3 miles west of Orland.

The outer border of the main moraine passes from Lagrange County into Steuben County on the south side of Pigeon River and crosses to the north side of the river at Flint River, 4 miles east of the county line. Thence its course is northward across the State line.

It is not easy to differentiate this main moraine from the Mississinawa morainic system which follows and laps upon its inner border. Dryer thinks that the greater part of the moraine belongs to the Mississinawa,[1] basing his opinion on its more regular surface and predominating clayey constitution; the irregular western edge he classes with the drift of the Saginaw lobe. The present writer finds evidence, however, in the distribution of outwash aprons and in the relation and connections of the several ridges of the irregular western edge that they also belong largely to the Huron-Erie lobe. (See pp. 163-164.) Dryer's line is probably not far from correct so far as it pertains to the limits of the Mississinawa system, which, from its bulk, is inferred to have overridden the earlier moraine. Possibly both have overridden a pre-Wisconsin ridge, for from studies in southeastern Michigan (see pp. 199, 261) there seems good reason to think that pre-Wisconsin drift forms a considerable part of certain massive moraines which are in line with and are apparently a continuation of this massive drift belt.

The general width of the morainic belt and of the Mississinawa morainic system, from their junction northeastward to the State line, is 10 to 15 miles, about the same as that of the moraines southwest of the junction. The combined moraines cover much of the eastern half of Noble County, about 30 square miles of the southeastern part of Lagrange County, about as much of the northwestern part of Dekalb County, and much of the western half of Steuben County. Their continuation in southeastern Michigan is considered in connection with correlative moraines of the Saginaw lobe. (See pp. 189-195.)

TOPOGRAPHY.

The moraines of the Huron-Erie lobe show a gradual and somewhat regular increase in altitude from southwest to northeast throughout their extent in northeastern Indiana. They are below 700 feet near Delphi, but reach 775 feet north of Logansport, 800 feet in northeastern Cass County, 900 feet in southeastern Fulton County, 1,000 feet in eastern Noble County, and 1,100 to 1,150 feet on the highest points in northern Steuben County.

From data furnished by deep borings it appears that the altitude of the bedrock surface does not rise toward the northeast, but is remarkably uniform at about 600 feet above sea level all along the morainic belt in northeastern Indiana. A few miles north of the State line, however, in Hillsdale County, Mich., bedrock rises very rapidly and attains an altitude of over 1,100 feet. The great drift accumulations in northeast Indiana are laid down, as it were, in the lee of the prominent table-land of sandstone of the Marshall formation that has its southern terminus in Hillsdale County, Mich.

In Whitley, Kosciusko, Fulton, Wabash, Miami, and Cass counties the moraines form the divide between Tippecanoe and Eel rivers, both of which are tributary to the Wabash. North of the head of the Tippecanoe the several headwaters of Elkhart River find their source in these moraines and lead northwestward to St. Joseph River and thence to Lake Michigan. The opposite or southeastern slope of the moraines is drained by tributaries of the St. Joseph (of the Maumee), which belongs to the Lake Erie drainage. In Steuben County these moraines are traversed from east to west by three small streams, Turkey Creek, Pigeon River, and Crooked Creek, which have their sources near its eastern border on much lower land than the main crest of the moraine. Their discharge is into St. Joseph River and thence to Lake Michigan.

In most places the drainage divide is at the crest of the main moraine, most of which is higher than the general level of the western edge, though some prominent points along the western edge are as high as the main crest. The relief of the main crest above the outer border district is generally between 50 and 75 feet and above the plain on the inner or eastern border 100 to 150 feet, the country to the southeast being lower than that to the northwest.

[1] Dryer, C. R., Eighteenth Ann. Rept. Indiana Dept. Geology and Nat. Res., 1894, pp. 83-90.

The topography of the southwestern portion of this series of moraines in Cass County and northern Miami County, Ind., is of a swell and sag type in which there are few basins. The swells are 10 to 40 feet in height and are closely aggregated, giving the moraines a strong expression compared with the nearly plane district to the northwest. Lake basins become conspicuous in southeastern Fulton and northwestern Wabash counties and continue numerous all along the morainal belt to the northeast. They are much more prominent on the northwestern or outer slope than on the southeastern or

inner slope and are especially numerous where moraines of the Saginaw lobe connect with these moraines. The largest lakes exceed a square mile in area, and one, James Lake, has an area of 2.6 square miles; the majority, however, cover but a small fraction of a square mile and some occupy but a few acres. Many of them have depths 50 to 75 feet or more below the level of the outlets and more than 100 feet below the surrounding parts of the moraine. James Lake, with a reported depth of 87 feet, has on its eastern border hills that rise more than 100 feet above the water surface, thus giving the basin a depth of about 200 feet below the neighboring hills. The highest knolls along the moraine are probably those in northern Steuben County, which rise more than 100 feet above bordering sags. Knolls 50 to 60 feet in height are found at short intervals as far southwest as northern Wabash County, but most knolls are only 20 to 40 feet high and many of them rise less than 20 feet above the bordering sags. On the inner slope of the moraines few knolls exceed 40 feet in height and the general expression is much less varied than on the outer slopes. Marshes and nearly plain tracts are also much less common on the inner slope than on the outer. In places on the outer slope sharp ridges known as “hogbacks,” some of which perhaps are to be classed as eskers, are not uncommon; they are, however, very short, none exceeding a mile in length having been observed. They commonly form the borders of lake basins; one lake in Steuben County has received the name “Hogback Lake” because of its close association with one of these ridges.

On the outer slope of the moraine deep indentations show where lines of glacial drainage lead away from the moraine. In Steuben County these glacial channels have their heads on the inner border of the moraine and thus completely traverse the moraine. One of them is occupied by Turkey Creek, another by Pigeon River, and a third by Concord Creek and a string of lakes tributary to Crooked Creek.

STRUCTURE OF THE DRIFT.

COMPOSITION.

It is somewhat difficult to set forth clearly the structure of this massive morainic belt because of the great differences it displays both horizontally and vertically. Extensive areas in the southwestern part and along the inner or southeastern slope of the belt are covered with clayey till, but many of them are underlain by thick deposits of sand and gravel. The clayey till is apparently thickest in the low-lying southwestern part of the belt in Cass and Carroll counties.

The outer slope of the belt of moraines shows extreme variability in surface structure, the deposits ranging from stiff clayey till to coarse cobble and gravel. There are no extensive areas of any one kind of deposit. However, gravelly and sandy drift seems to increase and clayey drift to decrease from the main crest of the belt toward the outer border. The gravelly and cobbly knolls and ridges are more or less definitely related to and grouped around the heads of the gravel plains that lead away from the moraines and that were formed by the waters discharged from the ice. Much of the drift on the outer slope is a loamy sand, not definitely assorted, but looser textured than the till of the main crest and the southeastern slope. Local occurrences of very stiff clay, however, were noted.

In northeastern Lagrange and northwestern Steuben counties a very sandy tract with uneven surface, containing both basins and knolls, rises abruptly at its western edge into an elevated gravel plain. This sandy tract was probably covered by the Huron-Erie ice at the time the higher gravel plain was building, or was perhaps occupied temporarily by a lake which was drained later by the cutting down of its outlet across the gravel plain. The sand might thus be an outwash from the ice, which settled in the bed of the lake. The district is sparsely settled and has only a few shallow wells, so the character of the material below the surface sand is not known.

South of Pigeon River considerable clayey till occurs between the Lagrange moraine and the more bulky moraine to the east in south Lagrange County, but its continuation into Noble County is loose textured.

BOWLDERS.

Bowlders are more plentiful and at the same time less regularly distributed on the outer than on the inner part of the morainic belt, but are not rare in either situation. The number on the outer part compares favorably with the number found in the several moraines of the Saginaw lobe (Maxinkuckee, New .Paris, Middlebury, Lagrange, and Sturgis), which connect with this morainic belt. One of the most striking accumulations in the region is found, however, not on the morainic belt but in the Wabash Valley near Logansport, in whose outskirts there are hundreds if not thousands of bowlders to the acre. As the Wabash is a comparatively weak eroding agent these bowlders must have been concentrated by the erosion of the moraine and the removal of its finer parts by the outlet of Lake Maumee. Some bowlders are scattered over the gravel plain on the outer edge of the morainic belt, good illustrations being found in eastern Lagrange County both north and south of the Pigeon River valley.

THICKNESS OF THE DRIFT.

Well data.—The search for natural gas about 1886 led to the making of several deep borings in the region traversed by this morainic belt. Though not successful in finding gas these borings throw some light on the structure of the drift in places where it is especially thick.

In the northern part of the district, in Steuben, Dekalb, Whitley, and northern Allen counties, the thickness of the drift is very great, but farther south it is relatively thin.

Ordinary wells for farm and domestic use reach rock in southern Allen, much of Huntington, southern Wabash, and all of Wells and Adams counties, except when in the line of deep preglacial valleys.

Steuben County.—Records of farm wells in eastern Steuben County show nearly continuous till to 100 feet and even to 150 feet. In places, however, as in the vicinity of Fish Lake in the southeastern part of the county, the drift is gravelly and wells are obtained at depths of 25 feet or less.

A well at the Tri-State Normal College in Angola, 104 feet in depth, may have been largely in pre-Wisconsin drift, for after penetrating 23 feet of yellow and blue till of the Wisconsin drift it entered a reddish stony till with sandy pockets too small to yield much water. This clay continues 75 feet to a water-bearing gravel at bottom. The ground here is about 35 feet lower than on neighboring knolls and ridges in the southern part of the village.

Many wells on the high part of the moraine from Angola southwestward are 80 to 100 feet and some of them are 160 feet in depth. They ordinarily penetrate loose-textured drift with a water table 75 feet or more below the surface. Some of them, however, are reported to have penetrated much blue till. Exposures along roadsides and in ravines show stony till of very loose texture.

Lagrange and Noble counties.—Numerous shallow flowing wells exist in southern Lagrange and northern Noble counties in a plain between the Lagrange moraine and the main moraine to the east. Most of them are on low tracts a few feet below the level of the bordering plain near Elkhart River and some of its tributaries, the head apparently being insufficient to give flows on the plain. Many are only 10 to 20 feet deep and the occurrence of flows from such slight depth seems all the more remarkable from the fact that there are no tracts markedly higher in the immediate vicinity to serve as or suggest the source of the artesian head. The elevation above sea level to which the water rises decreases 60 feet from northeast to southwest in the 8 miles from Wolcottville to Wawaka, being about 955 feet at Wolcottville, 930 feet at Rome City and in wells in secs. 3 and 10, T. 35 N., R. 9 E., and about 895 feet around Wawaka.

The underground relations are so little understood that it can not be stated that the wells are all in a single pool. A single well or a small group of wells may be controlled by local conditions in its catchment area and underground flow and be independent of the remainder of the wells. Possibly the catchment area or areas will prove not to be in the immediate vicinity but in a more or less remote district of higher altitude. In that case the shallow wells may strike water that rises through fissures in the till from considerable depth. Numerous springs along the shallow valleys in the plain around Wawaka may also prove to rise from considerable depth.

The deepest flowing well reported is 1½ miles west of Wawaka on the farm of John Pasch. The following record was obtained by Dryer:

Record of Pasch flowing well near Wawaka, Ind.

	Feet.
Gravel	6
Quicksand	40
Clay, blue	34
Gravel	2
Clay, blue	77
Gravel, cemented	7
	166

The shallow wells east and south of Wawaka, with depths of 10 to 20 feet, are driven through a few feet of clay and are apparently in sand or fine gravel at the bottom. One of the strongest, that of Abram Frank, a mile east of Wawaka in the east part of sec. 27, is only 10 feet deep and flows 2 or 3 barrels a minute. It fills a pond used for fish culture and then runs to waste in a stream that compares favorably in size with the neighboring brook into which it discharges.

At the Rome City sanitarium the wells range in depth from 16 to 40 feet and obtain their supply from gravel below blue clay. The head is 4½ feet above the level of the large reservoir at this village, or about 931 feet above sea level. The flowing wells at Wolcottville are 53 to 65 feet deep and penetrate 20 feet of surface gravel overlying blue till to the water bed. They are on low ground along Elkhart River and have a head only 5 feet above the surface.

Several wells on the west side of Elkhart River south of Eddy in secs. 3 and 10, T. 35 N., R. 9 E., range in depth from 60 to 88 feet. One at a schoolhouse in sec. 10 flowed when first made, but in 1902 the water lacked 2 or 3 feet of reaching the surface. The deepest well (88 feet) on the Conrad estate in sec. 3 flowed 5½ gallons per minute at 3 feet above the surface in 1902. These wells have about the same altitude as those in Rome City, 930 feet above sea level.

A so-called “blowing well” was noted at a farmhouse a mile south of Albion. The well is 68 feet deep and was largely through dry gravel and cobble. The blowing or whistling occurs when barometric conditions cause the air in the gravel to be expelled.

In northeastern Noble County at Kendallville a deep gas-well boring shows the drift to be 485 feet deep. Specimens of the drillings, preserved in a glass tube, show that the material is nearly all sand and fine gravel below 20 feet of yellow till. A record of a water well at Dr. Mayer’s residence in Kendallville, furnished by the driller, is as follows:

Record of Mayer well, Kendallville, Ind.

	Feet.
Clay, surface	5
Gravel, dry	20
Gravel, water bearing	10
Clay, soft, blue	25
Gravel, water bearing	20
Till, hard, bluish (pre-Wisconsin?)	70
Till, soft, blue	25
Gravel, water bearing	10
	185

Another well in Kendallville 108 feet deep did not strike the hard till.

A well 3 miles east of Kendallville, in sec. 1, T. 34 N., R. 11 E., penetrated yellow till to about 14 feet and then blue till with thin beds of sand or gravel to 206 feet. A well 4 miles northeast of Kendallville is reported to have penetrated nothing but till to 120 feet, but neighboring wells strike water-bearing gravel or sand at moderate depths.

A gas-well boring at Albion was observed during drilling by Prof. W. B. Van Gorder, who furnished the following record:

Record of drift beds at Albion, Ind.

	Feet.
Clay, yellow	10
Clay, blue	10
Sand and gravel	115
Clay, blue	20
Sand and gravel, with streaks of blue clay	52
Sand and gravel	81
Clay, blue, with thin beds of sand	52
Gravel	5
Bowlder clay, red	15
Sand	5
Slate (?)	1
Sand	9
Total (assorted material 267, clay 107, slate 1)	375

The boring penetrated till and assorted, material in alternating beds, of which the till comprises only 30 per cent and the assorted material 70 per cent. If the several drift sheets were widespread it might be concluded that there were stages of melting and outwash followed by readvance of the ice and deposition of till. But numerous natural exposures and well records show that the till grades horizontally into gravel or sand and back again to till within short distances. Local conditions within and beneath the ice instead of great oscillations of the ice border seem to have determined the character of the beds.

At Ligonier, in northwestern Noble County, the drift is known to be only 169 feet. No further data were obtained.

Kosciusko County.—Two gas-well borings at Warsaw penetrated 247 and 255 feet of drift. A boring 3 miles west of Warsaw penetrated 243 feet of drift. In all three borings sand and gravel greatly predominate over the till. In one well water was flowing strongly from the top of the 7-inch pipe 2 feet above the surface at the time of the writer's visit. As the water contains much sulphureted hydrogen, a portion of it at least is from the rock. It is thought, however, that much of it is from the drift.

Whitley County.—At Larwill, on an elevated part of the moraine 103 feet higher than Warsaw, there is 365 feet of drift. The upper 100 feet is chiefly rather clayey till, overlying mainly sand and gravel. Records of two other deep wells east of this moraine belt are presented on page 171.

OUTWASH.

OUTWASH IN INDIANA.

DISTRIBUTION AND CHARACTER.

Swampy and somewhat sandy tracts that set in on the outer or northwest border of this morainic belt near Lake Cicott and continue 7 or 8 miles eastward to the head of Crooked Creek north of Logansport seem to be outwash from it. Sand appears also in a ridge several miles in length that borders and to some extent rides upon the outer slope of the moraine; but this was probably drifted up by the wind. Northeastward from the head of Crooked Creek, across northern Cass, southeastern Fulton, and southwestern Kosciusko counties little outwash is found until the Tippecanoe Valley is reached near Warsaw, the moraine in this interval of about 30 miles fronting on a plain of clayey till. From the Marshall-Kosciusko county line eastward along the Tippecanoe Valley to Warsaw a sandy and gravelly plain lies mainly south of the stream and apparently rises toward the moraine whose edge is 1 to 3 miles south. The material in this plain is fine, indicating rather weak discharge, and its extent is small, for it becomes inconspicuous in western Kosciusko County.

Farther up the Tippecanoe across Bone Prairie and Turkey Prairie eastward to Tippecanoe Lake a sheet of gravel of medium coarseness, spread over about 50 square miles, may have been in part outwash from the Saginaw lobe. Farther east in the vicinity of the Barbee Lakes and Tippecanoe Lake the outwash is sandy.

A conspicuous gravel plain south of Elkhart River in western Noble County abuts at the east against sharp morainic ridges of the Lagrange moraine and at the north fronts on a bowlder-strewn plain along Elkhart River. Its position indicates derivation from the Saginaw as well as from the Huron-Erie lobe, and this interpretation is sustained by the character of the material and the slope of the plain. The material is a coarse gravel and cobble on the north and east and becomes a fine gravel toward the southwest, and the plain slopes southwestward. That the Huron-Erie lobe probably persisted longer than the Saginaw has already been indicated, and is apparently supported by certain features of this gravel plain, on whose southern edge a shallow but broad valley heading in the Huron-Erie correlative of the Lagrange moraine east of Cromwell seems to have been produced by drainage from the Huron-Erie lobe after the cessation of the outwash from the Saginaw lobe.

A plain lying along the outer border of the Lagrange moraine between the Elkhart Valley at Ligonier and the intersection of the Huron-Erie with the Lagrange moraine near Lagrange is covered in part by a thin deposit of clay or clayey till but generally has gravel and sand at the surface. In the clayey portion the sand and gravel are sufficiently near the surface to give underground drainage. The clay is present from near Ligonier northward past Topeka and extends 2 or 3 miles out from the moraine, terminating in a feather edge. It carries a few surface bowlders and is probably to be regarded as a till sheet, though in places nearly free from pebbles. The gently undulating western slope of the moraine near Topeka also has a clayey till of considerable depth. The conditions here are the reverse of those common in outwash aprons, in most of which

sand and gravel extends up to the moraine as a continuous surface sheet and even laps upon the edge of the moraine as a coating to the knolls and as a filling in sags. Here, however, the outer slope of the moraine is nearly free from surface gravel and the till extends out into the gravel plain. West and southwest of Topeka wells with depths of 50 to 75 feet are entirely through gravel and sand after passing through the thin surface capping of till. This district is known as the "Haw patch" and is one of the most productive farming areas in Indiana.

Within 2 or 3 miles northeast from Topeka sandy deposits set in on the outer edge of the moraine, but soon give place to gravel and cobble which extends to the head of the reentrant between the Lagrange moraine and its equivalent in the Huron-Erie lobe. It is naturally to be expected that drainage here would have been exceptionally vigorous. The strongest out-flow (see p. 145) appears to have been from the Huron-Erie side of the reentrant.

East of the Lagrange moraine in northern Noble County gravelly plains of limited extent appear at two places, but in general no conspicuous outwash lies along this part of the moraine. One gravelly plain with an area of 3 or 4 square miles lies along the east side of the south fork of Elkhart River in the north part of T. 34 N., R. 9 E. Its surface is not so level as that of the typical outwash apron, but shows gentle swells 5 to 10 feet high and marshy basins, some of which are occupied by lakes. Within a mile southeast of the edge of this gravelly district a very stiff clayey till sets in and extends southeastward beyond Albion. North and northeast of the gravelly district a very loose textured till extends to the north fork of Elkhart River and Waldron Lake.

The second gravelly district extends westward from Rome City into the bend of Elkhart River. It is a pitted plain near its eastern end and has sags and poorly drained depressions interspersed with dry strips of gravel. North of this gravel plain a sharply rigid strip of rather loose textured drift trends east-southeast and west-northwest. Possibly the gravel plain was formed as an outwash during the development of this ridged belt, for the latter has a more strongly morainic aspect than the drift on the immediate southeastern and southern borders of the gravel plain. The record of a deep well on the Rhinehart farm, 2 miles west of Rome City, shows sandy gravel, with water in its lower half, extending to 52 feet, 40 feet of blue till, and 24 feet of water-bearing sandy gravel, giving a total depth of 117 feet.

GLACIAL DRAINAGE.

In eastern Lagrange and northwestern Steuben counties conspicuous gravel plains lie along the northwestern border of the main moraine each side of Pigeon River. The portion south of the river in eastern Lagrange County contains coarse gravel and cobble and is coated to a considerable extent by a thin deposit of earthy material in which large bowlders are embedded. It stands 30 to 40 feet above a sandy tract along the river. In respect to bowlder capping, as well as in altitude, it is similar to the high plain north of Mongo, discussed in connection with the Sturgis moraine (p. 150). The ice sheet apparently occupied this, gravel plain and that north of Mongo while depositing the surface capping of bowldery material. Its recession from this plain seems to have been somewhat irregular. The lower district along Pigeon River, it is thought, held a mass of ice in the district east from Mongo for some time after the ice had withdrawn from the higher districts south of it. Otherwise it should have been built up to a level corresponding to that of the higher plain. In northwestern Steuben County the high plain is more sandy than in eastern Lagrange County, and in places it carries low dunes. It extends back into recesses in the moraine at the Pigeon Valley and farther north at Gage Lake. In these recesses, as well as along Turkey Creek in eastern Lagrange County, it is moderately trenched by lines of glacial drainage that lead through the main moraine from a lesser moraine on its inner border.

The line of glacial drainage in the Turkey Creek valley heads at Little Turkey Lake on the southern edge of Steuben County, about a mile west of Hudson-Ashley. In its course through the large moraine it occupies a valley whose general width is nearly a mile, though somewhat narrower near the outer border of the moraine near Springfield (or Brushy Prairie). A chain of lakes is found along its course, one of which, Turkey Lake, is 75 feet in depth. It is probable that stagnant ice masses persisted at the site of these lakes during the deposition of the sandy gravel in this line of glacial drainage.

Pigeon River was utilized as a line of glacial drainage until the ice had withdrawn to the Wabash moraine, which lies east of and is distinct from the moraines under discussion. The present stream follows the outer border of the Wabash moraine southward for about 12 miles, and then turns westward to enter the main moraine of the belt under discussion about 3 miles below the village of Pleasant Lake. It emerges from this moraine 6 miles farther down, at Flint, and traverses a gravel plain for the remainder of its course, except at Mongo, where it passes the weak outlying moraine of the belt. It has in its passage through the main moraine a valley about one-half mile in width, with bluffs 30 to 50 feet high from which there is a rise into the moraine. Along its course through the main moraine it flows through a chain of lakes, of which Long, Golden, and Hogback lakes are the largest. Hogback Lake has its longest diameter athwart the course of the channel and extends back into the moraine at either end, but Long and Golden lakes have their longer axes in harmony with the axis of the channel. The gravel and sand of the glacial drainage line form a low terrace along the stream and around the borders of the last-named lakes, but are completely interrupted at Hogback Lake. The lakes are about 40 feet in their deepest parts and in all probability occupy basins in which stagnant masses of ice persisted during the use of the channel as a line of glacial drainage.

A third line of glacial drainage that traverses the main moraine is found in a plain that sets in about 3 miles north of Angola and leads westward. This plain is bordered on the east and south by a gently undulating till tract and on the north by a very prominent morainic accumulation carrying points that rise 100 feet above the plain and nearly 1,150 feet above sea level. The plain is about a mile wide and extends westward from secs. 11 and 14, T. 37 N., R. 13 E., to Crooked Lake in secs. 9 and 16 of the same township. It also touches on the north the southern end of James Lake. The main line of discharge for glacial waters appears to have been over the basin occupied by Crooked Lake, for the gravelly plain is continued at the western end of the latter. It passes across the basin of Gage Lake, where it emerges from the main moraine. Gage Lake is bordered on the northeast by another gravel plain, whose surface is 45 feet, by hand level, above the water, and is 25 feet above the surface of the plain along the Crooked Lake outlet. As the depth of water reaches 70 feet the bottom of the basin is 115 feet below the higher gravel plain and 90 feet below the lower plain. Crooked Lake is in a shallower basin, its bed being scarcely 50 feet below the bordering gravel plain at its eastern end. The plain that heads east of Crooked Lake has a sandy gravel and seems not to have been formed by very vigorous drainage. The higher plain that sets in at the east end of Gage Lake carries much cobble and coarse gravel and seems to have been at the head of a vigorous point of discharge.

OUTWASH IN MICHIGAN.

A gravel plain having an altitude of about 975 feet at the Michigan State line descends northward to about 920 feet at Prairie River, 2 miles south of Bronson. North from Prairie River the plain is shown by the drainage and by barometric determinations made by W. F. Cooper to be a little higher on its eastern than on its western border, being about 940 feet on the east and 920 to 930 feet on the west. The slopes, therefore, seem to support the view that the plain was built up in large part at least by outwash from the Huron-Erie lobe on its eastern side rather than by outwash from the Saginaw lobe, as it receded lengthwise of the plain. The character of material is in harmony with this interpretation, cobble and coarse gravel being more conspicuous on the southeastern edge of the plain than elsewhere. Prairie River finds its source in a large marshy plain that extends up into the moraine about to the State line, and that seems to have been a place of discharge from the ice after the latter had receded a few miles from the position it held while the large gravel plain was forming.

Another extensive gravel plain heads in the midst of the main moraine of this belt just north of the State line in the southeastern township of Branch, County, Mich., and extends northwestward to join the one just described near Coldwater. For 10 miles from its head its average breadth is about 4 miles and its maximum nearly 6 miles. Farther north it is reduced to a width of about a mile and is bordered by distinct bluffs, as if trenched by a stream. The broad gravel plain is not bordered by definite bluffs. The plain has numerous dry basins near its head and farther down it contains several lakes, the largest of which, Coldwater Lake, has an area of about 2 square miles. Considerable cobble and coarse gravel occupies the head of this plain in the vicinity of the hamlet of California, becoming finer northwestward or down the slope of the plain. The altitude at the head of the plain is 1,020 to 1,030 feet, as determined barometrically by W. F. Cooper, but it drops to about 975 feet at the south end of Coldwater Lake, or about 50 feet in 5 or 6 miles. Farther north the descent is more gradual, being only 70 feet from Coldwater Lake along the Coldwater Valley to the St. Joseph Valley at Union City, a distance of fully 20 miles.

From Coldwater Lake a sandy strip 1 to 2 miles wide runs northeastward to Quincy. In it there is a chain of lakes, of which Marble Lake near Quincy is the largest, its area being little less than that of Coldwater Lake. This sandy strip is probably a line of glacial drainage, though at present the water divides about midway of its course, and the altitude seems to be slightly higher toward the northeast than toward Coldwater Lake. From Marble Lake there may have been glacial drainage southwestward through this sandy depression to Coldwater River at Coldwater Lake, and also westward to the same stream near the city of Coldwater. The outwash from Quincy northwestward along the border of the Tekonsha moraine is discussed in connection with that moraine (p. 152).

INNER BORDER.

DISTRIBUTION OF THE MORAINES.

The district east of this morainic belt in northeastern Indiana was discussed in some detail in Monograph XLI, and only a few general observations seem necessary here. The Mississinawa morainic system and the Salamonie, Wabash, and Fort Wayne moraines come into Indiana from northwestern Ohio separated by intervals of 10 to 15 miles and follow nearly parallel northwestward courses to the main axis of the Maumee-Wabash basin. Beyond this axis they turn northeastward and their parallelism is less marked. The outer two moraines are somewhat distinct from each other and from the great morainic system outside as far north as Columbia City, beyond which they coalesce and bank up against the inner face or slope of the great morainic system. The inner two lie closer together in this northern district than in the district south of the axis but remain distinct from each other and from the moraine outside throughout their course in northeastern Indiana. St. Joseph River (of the Maumee) flows between them. In southeastern Michigan all these moraines merge with the great interlobate belt that follows the “thumb” of Michigan and separates the Huron-Erie from the Saginaw lobe.

MISSISSINAWA MORAINIC SYSTEM.

The Mississinawa morainic system has a general width of 5 or 6 miles and is in places separable into two or more moraines, between which are narrow stretches of till plain. It has a swell and sag topography with few sharp knolls and few basins where not combined with the greater morainic system. Its relief above the outer border plain ranges from 20 to 75 feet and its front is rather steep. Its drift is largely a clayey till and carries much fewer bowlders than does the large morainic system with which it becomes blended at the north. This morainic system correlates somewhat closely with the Kalamazoo morainic system of the Saginaw and Lake Michigan lobes. Its outer border is followed by Mississinawa River, from the Ohio-Indiana State line northwestward nearly to the Wabash, and it is because of its close association with this stream that it has received the name Mississinawa. The bordering plains on either side of the system are of stiff clayey till and their surface is nearly free from knolls or noteworthy features.

SALAMONIE MORAINE.

The Salamonie moraine has scarcely half the average breadth of the Mississinawa system and in its northern part is in places only 1 or 2 miles broad. At several places along its course it bears groups of conspicuous gravelly knolls, some of which are 60 to 80 feet high. Its greater part, however, presents a subdued swell and sag topography, the swells being only 15 to 20 feet above the sags. North of Wabash River, in southern Whitley County, it is reduced to a low, rather smooth ridge differing but little in topography from the border plain but having a larger number of surface bowlders. The moraine is followed on its outer border throughout much of its course from the Ohio line to Wabash River by Salamonie River, from which it takes its name. There is no continuous gravel plain along the border of the moraine, but the amount of gravel and sand is greater than it is along the Mississinawa system.

WABASH MORAINE.

The Wabash moraine is similar to the Mississinawa system in topography and governs the course of Wabash River from near the Ohio line northwestward to where the river turns westward down the axis of the Maumee-Wabash basin. Its breadth is but 2 to 4 miles. It has an abrupt outer-border relief of 20 to 50 feet along much of its course from the State line to the axis of the basin, but from the axis northward its relief is less conspicuous and seldom exceeds 20 feet. This moraine not only controls part of the course of the Wabash, as indicated above, but in its northern extension partly controls Aboit River, Cedar Creek, and Pigeon River. Each stream in turn follows it for some distance; Pigeon River turns westward to pass through the great morainic system; Cedar Creek turns eastward through the Wabash moraine to enter the St. Joseph, (of the Maumee), and Aboit River passes directly down the axis of the basin along the old outlet of the glacial lake Maumee to Wabash River. Very little sandy or gravelly outwash is seen on the outer border of the Wabash moraine, the streams having their courses through till plains. Some sand and gravel occurs along the Pigeon. A gravel plain on the outer border of this moraine a few miles north of Fort Wayne at the head of Eel River seems to be an outwash from it. The drainage for glacial waters from the southwest-flowing part of Cedar Creek may have been across this gravel plain to Eel River. It is probable also that the Wabash afforded a line of escape for the glacial waters in the vicinity of the axis of the basin.

FORT WAYNE MORAINE.

The Fort Wayne moraine follows the north side of the St. Marys River valley from the Ohio line northwestward to Fort Wayne, and the east side of the valley of the St. Joseph (of the Maumee) from Fort Wayne northeastward into northwestern Ohio. It has a general width of 3 or 4 miles and presents a gently undulating surface with less strength of expression than any of the other outlying moraines of this series. Its main crest is 50 to 75 feet above the beds of the streams that follow the outer border. The streams are in shallow trenches usually 20 to 30 feet deep and the moraine has a relief of 30 to 50 feet above the bluff or plain bordering the valley. The outer slope is a mile or more across, being scarcely as steep as in the moraines outside. The drift in this moraine is largely a clayey till and carries but few bowlders on its surface. The moraine may have had some outwash into the St. Joseph Valley, along which there is a strip of gravelly land; but wells show that the gravel extends to great depth and that it appears to pass under the till of the moraine. Probably only the surface portion, including perhaps that standing above the level of the present stream, is to be correlated with the Fort Wayne moraine. These gravel deposits extend beyond the mouth of St. Joseph River into the bend of St. Marys River in the west part of Fort Wayne. There is no evidence of vigorous outwash into the St. Marys Valley above Fort Wayne.

AREA EAST OF THE FORT WAYNE MORAINE.

By FRANK B. TAYLOR.

The area east of the Fort Wayne moraine is described by Mr. Leverett in an earlier report,[1] but the completion by the United States Geological Survey of topographic maps covering the district between Findlay and Delphos, Ohio, made a reexamination very desirable. The area is one in which the beaches of Lake Maumee approach the front of the Defiance moraine near Findlay and appear to afford excellent opportunity for the study of the deforming effect of ice attraction on contiguous lake waters. (See pp. 342-346.) The writer spent a short time studying this and related areas in 1908 and 1909.

Although the recent detailed studies in this area are very incomplete and fragmentary, the results are important for several reasons. Hitherto the interval between the Fort Wayne and Defiance moraines has been represented as devoid of terminal moraines. This stretch of 45 miles is unusually wide for an intermorainic space and has been something of a puzzle to glacial geologists for many years. The studies recently made seem to show that this interval is in fact occupied by several faint terminal moraines, most of which, so far as known, are crowded into the western part of the area and seem to be closely related to the Fort Wayne moraine as previously mapped.

At least two faint moraines pass through that area between the Fort Wayne and Defiance moraines. They run in courses nearly parallel with the main or frontal crest of the Fort Wayne moraine in the vicinity of Lima, Ohio, and appear to be related to it. One of them passes west from Mount Cory to Bluffton, where it turns southwestward and passes a mile or so south of Cairo and Elida; this may be called the Bluffton moraine. Another fainter ridge runs west from Rawson and curves to the southwest roughly parallel with the Bluffton moraine and 2 or 3 miles north of it; this may be called the Rawson moraine. The Bluffton moraine is so clearly developed as a distinct individual that it seemed worth while to look for others and if possible to work out their relations to the Fort Wayne moraine and to Lake Maumee. It was not possible to do this in detail, but the general relations were made out.

[1]Leverett, Frank, Glacial formations and drainage features of the Erie and Ohio basins: Mon. U. S. Geol. Survey, vol. 41, 1902, pp. 566-581.

It was thought at first that the passage of one of these moraines beneath the level of Lake Maumee might account for certain peculiarities of the Maumee beach, especially for its northward bulge between Delphos and Van Wert and perhaps for other similar features between Van Wert, Ohio, and New Haven, Ind.

The investigation was not carried far enough to test this matter fully. It was found that the northward bulge of the beach east of Van Wert is in all probability due to a moraine passing lakeward, but this moraine was not identified with either the Bluffton or the Rawson moraines, but appears to be inside of both of them and of later date. The area west and northwest of Lima was not examined in enough detail to make sure of the identity of the Bluffton and Rawson moraines west of Ottawa River. But west of the meridian of Delphos more moraines of the same character and having the same relations to the Fort Wayne moraine were found and followed into Indiana. Besides the faint moraine which causes the bulge of the shore east of Van Wert, there is another which passes northwest from Conway, Ohio, and affects the shore slightly; it is probably continuous with a faint ridge 1½ miles south of Van Wert.

At Landeck, 3 miles southwest of Delphos, there is a ridge which becomes distinct a mile or so northwest of Venedocia and runs thence unbroken to or beyond Monroeville, Ind. Through much of this distance, especially toward the northwest and in Indiana, this ridge is distinctly double and throughout nearly the whole distance it is sharply defined by a well-developed channel of ice-border drainage along its front. The flat floor of this drainage line is well developed at the south edge of Venedocia and is easily followed for 2 miles westward to Little Auglaize River. Long Prairie ditch, which comes in from the west at this point, follows the bed of this glacial stream in a reverse direction. The channel itself continues west, passing a mile north of Ohio City and past Glenmoore, receiving headward tributaries of Town Creek between these two towns. North of Glenmoore the moraine turns northwestward, but the drainage channel continues westward to Wren and thence southwest through the front ridge of the Fort Wayne moraine to St. Marys River. From Glenmoore northwest to Middlebury and perhaps to Wolfcale the ground in front of the moraine is a flat floor without any evidence of border drainage, but near Wolfcale a smaller border drainage channel begins and is particularly well defined from Wolfcale to Monroeville between the two parallel ridges of the moraine.

Eastward from Venedocia the moraine is somewhat fainter to Auglaize River, 1 mile northeast of Southworth. The drainage channel also becomes fainter in the same interval and was not clearly made out at Southworth, but it may be there, nevertheless, for the tract between Southworth and Cairo has not been examined. This ridge between Venedocia and Monroeville appears to lie inside of and hence is probably later than the Bluffton moraine, but may be the westward continuation of the Rawson.

In Ohio, west of Auglaize River through southern Van Wert County, the minor drainage strongly suggests another moraine and line of ice-border drainage between the one just described and the main ridge of the Fort Wayne moraine, which runs close along the north side of St. Marys River; and the same suggestive arrangement of drainage continues in Indiana to the Maumee River. Indeed, the minor drainage southwest and west of Monroeville indicates two and probably three ridges between the Monroeville ridge and the front or main ridge which passes just west of Hoagland, Ind.

In the eastern part of Allen County, Ind., another moraine, well defined for its type, runs southeastward from Gar Creek, passes just south of Dawkins, and, after crossing the State line into Ohio, passes southeastward between Magill and Batson. This moraine lies 5 miles northeast of the ridge at Monroeville and is very different from it in character. It is water-laid and finds physical expression only as a very low, smooth swell or ridge in the fiat plain of the old lake floor. It is, however, very persistent and characteristic in its relation to the valley slope. It has a definite trend in a broad graceful curve and controls the minor drainage. The observations thus indicate that there are at least six or seven weak ridges inside of the main front ridge of the Fort Wayne moraine.

The investigation on the north side of the Maumee Valley was less complete than that on the south side, but two and possibly three such ridges were found and two others seem to be indicated by the drainage lines. One moraine in particular is clearly developed just west of Bryan above the upper Maumee beach and was easily traced northeast to a point east of Alvordton and southwest to a point beyond Farmers Center. Throughout the whole distance this moraine is bordered along its front by a sharply cut drainage channel one-eighth to one-fourth mile wide, and it crosses divides between streams without interruption. The investigation was not carried far enough, however, to make sure of its identity southwest from Farmers Center. Faint morainic fragments between Fanster, Ind., and Link, Ohio, on the north side of Maumee River appear to be a northeastward extension of the moraine southeast of Gar Creek and possibly connect with the moraine west of Bryan; but this correlation is not yet established.

The country slope from the main ridge of the Fort Wayne moraine is shorter and therefore steeper on the north side of Maumee River than it is on the south side. From this fact it would be expected that any weak moraines on the north side would be more closely set together and perhaps less readily distinguished as individuals. So far as made out the series on the north side seems to correspond in a general way to that on the south side, indicating a symmetrical disposition of the ridges; but actual identification was not made.

Minor drainage concentrates along a line running north from Sherwood and turning gradually eastward past Ney and Glenburg. This fine was found on examination to be characterized by scattered low knolls and scattered bowlders protruding from a plain composed largely of lake clay without bowlders. This apparently marks the course of another moraine distinctly inside the Gar Creek ridge. It is not improbable that still another, perhaps largely concealed under lake clay, runs south between Powell Creek and Auglaize River. If there is a moraine between these streams it probably passes near Arthur and Continental, crossing the Blanchard River near Leon and curving gradually eastward north of Kalida and Pandora. The drainage strongly suggests a faint drift ridge in this position, but it has not yet been fully traced in the field. The moraine west of Bryan is perhaps to be correlated with the "Middle moraine," or outer Defiance ridge, which Mr. Leverett[1] found between the Fort Wayne moraine and the inner Defiance ridge in the Ann Arbor area.

Although incomplete, this investigation shows that the Fort Wayne moraine like the Port Huron morainic system is composite and is made up by the merging together of a number of ridges into a single broad belt. The Defiance moraine in Ohio has not been studied from this point of view, but its breadth and strength strongly suggest composite form also, and it is known to be double in part of the Ann Arbor quadrangle. The Defiance, however, is so extensively water-laid that its constituent ridges may not be distinguishable, unless in such forms as the faint bowldery belts which Sherzer has found in Monroe and Wayne counties, Mich.

WELL DATA.

By Frank Leverett.

Dekalb County.—Over the greater part of Dekalb County a sheet of till extends to an average depth of about 50 feet. Below the till the drift appears to be largely sand and gravel. The gas-well boring at Butler, in the northeast part of the county, is reported by Dryer to have penetrated the following beds. The compact clay near the bottom of the drift and the overlying red quicksand are probably pre-Wisconsin. It seems not unlikely that much of the great body of gravel and coarse sand is also pre-Wisconsin.

[1]Ann Arbor folio (No. 155), Geol. Atlas U. S., U. S. Geol. Survey, 1908. See also revised edition of 1915 and p. 280 of present report, where the names outer Defiance ridge and inner Defiance ridge are applied.

Record of drift beds in gas boring at Butler, Ind.

	Feet.
Hardpan (till)	15
Gravel and coarse sand	275
Quicksand, red	40
Clay, compact	45
Cobblestones and bowlders	3
	378

Most water wells in the vicinity of Butler obtain their supply from depths of 20 to 35 feet, though a few of them go down 150 feet. In the northern part of the county, 6 or 8 miles northwest from Butler, wells penetrate till for 60 or 80 feet before striking water-bearing gravel or sand. A well 3 miles south of Hudson penetrated 75 to 80 feet of till.

At Waterloo the drift at the gas well is as follows:

Record of drift in gas well at Waterloo, Ind.

	Feet.
Till	40
Sand and gravel, with water	270
Clay, blue, with pebbles	45
Gravel and cobble	10
	365

At Auburn two gas wells each penetrate about 280 feet of drift, which is largely till in its tipper half and largely sand and gravel in the lower half.

A few shallow flowing wells in the vicinity of Auburn on low ground on the border of Cedar Creek obtain water from gravel below the till. The head is seldom more than 2 to 5 feet above the surface.

The gas-well boring at Garrett penetrated about 50 feet of till, 200 feet or more of sand, and a thin bed of gravel at the bottom. The sand and gravel afford a large amount of water. In Garrett many wells obtain water at 40 feet, but some go down 75 to 100 feet. North and west from Garrett are extensive marshes with sandy borders, where wells are obtained at slight depth without entering the till.

Along the Cedar Creek valley, in the southern part of Dekalb County, water is usually obtained at 30 to 40 feet. The wells penetrate more gravel than till, though both are present.

A well 110 feet deep, in the southeastern part of the county near the village of St. Joe and but a few rods from the bank of the river, is mainly through sand and gravel.

A well on the farm of Christian Hirsh, east of St. Joseph River, near Spencerville, has the following section. In the same neighborhood perhaps a dozen other wells go down 60 to 100 feet, mainly through till.

Record of well near Spencerville, Ind.

	Feet.
Till, yellow	10
Till, blue	59
Sand, fine	120
Gravel	9
	198

Whitley County.—The Columbia City gas-well boring penetrated 224 feet of drift, mainly sand. A farm well on the plain in the southeastern part of the county reached a depth of 202 feet without striking rock. It penetrated 67 feet of clayey till, below which for 130 feet were alternations of sandy gravel with beds of till. Water is from gravel at bottom. In the southeastern part of the county the wells pass through a general coating of till 50 to 60 feet thick to strike a good supply of water; many of them are 60 to 80 feet in depth. Along the Eel River valley, however, there is a strip of gravel and sand in which wells obtain water at about river level.

Allen County.—In Allen County, of which Fort Wayne is the county seat, the drift is probably more than 200 feet thick on the northern border but decreases to about 75 feet at the southern border and in places to 20 or 30 feet; throughout the southern half its general thickness is 75 to 100 feet. At Fort Wayne it is 60 to 125 feet or more. The surface portion of the drift is generally a stiff clayey till; the only prominent exceptions being the gravel plain in the northeast part of the county, which connects Cedar Creek valley with the head of Eel River, and the narrow belt along the St. Joseph. In the northwest quarter of the county the till is generally underlain by water-bearing gravel at 25 to 35 feet, so that deep wells are unnecessary. In the northeastern part the till is thicker and many wells go 60 to 75 feet to the first water-bearing gravel. From Fort Wayne eastward past New Haven a few wells are stink to rock at 80 feet or less, but others draw from gravel beds between till sheets at 25 to 35 feet. In the old outlet of Lake Maumee, which leads past Fort Wayne to the Wabash at Huntington, there is sand and silt in places, though parts are floored with bowldery till. In the southeastern part of the county gravel beds within the drift furnish water at 30 to 40 feet or less, and in the southern and southwestern parts waterbearing gravel in many places underlies till at 20 or 30 feet. On the Wabash moraine, in the southern part of the county, many wells reach depths of 75 to 100 feet, but on the plain east of it few exceed 50 feet.

Flowing wells may be obtained along Maumee River from Fort Wayne eastward past New Haven. There are already one or more in Fort Wayne. The waterworks at New Haven is supplied from a flowing well 300 feet deep, which draws from rock, the drift being only 82 feet deep.

Adams County.—In Adams County, which lies south of Allen, the moraines and the plain tracts present a nearly continuous sheet of clayey till, there being little or no gravel outwash from the moraines and few gravel knolls. As a rule the drift is thin with a general depth of about 50 feet: where it is thick considerable sand and gravel is found in its lower portion. The great depth of the buried valleys in this region is shown by a gas-well boring at Geneva, which passed through 350 feet of drift, although, within a mile of the boring, rock outcrops at an altitude as great as the well mouth. In this boring the upper 80 feet was mainly through till; and the remaining 270 feet mainly through sand and gravel. Although the surface of the drift, through-out the county, is mainly till, wells show that water-bearing gravel is widespread beneath it at depths of 20 to 50 feet.

Wells County.—Wells County, which lies west of Adams and south of Allen counties, has a somewhat uniform sheet of clayey till at surface, with thin beds of sand or sandy gravel included in or underlying it. The average thickness of drift for the county probably does not exceed 50 feet, and rock is common at 30 to 50 feet.

Huntington County.—Huntington County, which lies west of Allen and Wells counties, has comparatively thin drift south of Wabash River, a depth of 100 feet being encountered in few wells. Northward from the Wabash the thickness increases to fully 200 feet on the northern border of the county. Clayey till forms the surface of the county, but gravel or sand prevails near the base of the drift and occurs as local beds in the till, causing neighboring wells to differ greatly in section. Flowing wells are obtained along the Salamonie Valley in the vicinity of Warren at depths of 65 to 100 feet. All are reported to derive their supply from limestone, but water is decidedly chalybeate, and drift water may have access.

Wabash County.—Wabash County is very similar to Huntington, which it adjoins on the west, both as regards the drift structure and the thickness. The northern end has very thick deposits, probably exceeding 300 feet, the thickness at North Manchester, in the Eel River valley, being 274 feet. The thickness in the southern portion probably averages less than 100 feet, but is much greater in the buried valleys, in one of which, at Lafontaine, it measured 300 feet. The only gravelly districts worthy of note are in narrow strips along the valleys of Wabash and Eel rivers. The till on the Mississinawa morainic system in places extends to depths of 100 feet or more, though usually water-bearing gravel and sand is found within 50 feet of the surface. Near New Madison, in sec. 11, T. 29 N., R. 7 E., a well passed through 160 feet of till and struck rock at 181 feet, and in sec. 26 two others penetrated similar amounts of till. On the plain west of the moraine most wells penetrate till for 25 feet or more before striking gravel or sand.

Grant County.—In Grant County, which lies south of Wabash and Huntington counties, the surface portion of the drift is a clayey till. West from the Mississinawa system the drift is thin, often but 20 feet or less in depth, but from that system eastward the thickness generally exceeds 100 feet and may average 150 feet. In the preglacial valleys it is 300 feet. Where the drift is thick the deeper portions are often largely of sand and gravel.

Blackford County.—In Blackford County, as in northeastern Grant County, the drift is 100 to 150 feet thick. In the northeast corner, however, over a few square miles along Salamonie River, it is but 20 or 30 feet thick. The main part of the drift is a clayey till, but beds of sand and gravel at various depths supply water for the wells. The deeper borings show thin beds of sand in the till.

Jay County.—Jay County, which lies east of Blackford and extends to the Ohio State line, is traversed by the Mississinawa and Salamonie moraines. The former is very largely of clayey till and the latter carries gravel knolls only locally. North of the Salamonie moraine the drift is thin, with rock at 10 to 20 feet. The drift is only 30 to 60 feet in the vicinity of Portland, the county seat, which stands between the two moraines. Along the moraines its thickness probably averages about 100 feet. In preglacial valleys it reaches a depth of about 350 feet. Where thickest and especially in the preglacial valleys its lower part is largely sand and gravel.