DEPARTMENT OF THE INTERIOR

MONOGRAPHS
OF THE
United States Geological Survey

VOLUME LIII

WASHINGTON
GOVERNMENT PRINTING OFFICE
1915

UNITED STATES GEOLOGICAL SURVEY
GEORGE OTIS SMITH, Director

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

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AND
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WASHINGTON
GOVERNMENT PRINTING OFFICE
1915

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By FRANK LEVERETT.

KALAMAZOO MORAINIC SYSTEM OF LAKE MICHIGAN LOBE.

ERRONEOUS CORRELATION.

Investigations pursued since the publication of Monograph XXXVIII have shown that certain moraines in southwestern Michigan which were assigned therein to the Saginaw lobe were really produced by the Lake Michigan lobe. The principal errors of interpretation are found on pages 340 to 342 and Plate XV of that monograph. Certain constituents of the drift and the relation of till plains to moraines in the district immediately east of the Valparaiso morainic system led the writer astray in the interpretation of the border between the Saginaw and the Lake Michigan lobes. Later studies have shown that a prominent morainic system, the Kalamazoo, which lies farther east than the border outlined in Monograph XXXVIII was formed by the Lake Michigan lobe. Under the old interpretation the Kalamazoo morainic system was considered a

northward continuation of the Maxinkuckee moraine of the Saginaw lobe, but really it is correlated with a younger morainic system of that lobe, connecting with it a few miles north of Kalamazoo, Mich. The writer regrets that so serious an error was introduced in this earlier publication.

COURSE AND DISTRIBUTION.

The Kalamazoo morainic system of the Lake Michigan lobe connects with its correlative of the Saginaw lobe in southwestern Barry County, Mich., 15 to 20 miles northeast of the city of Kalamazoo, the village of Prairieville being in the head of the reentrant angle between the two lobes. The Kalamazoo system embraces two well-defined ridges separated by a nearly continuous but very narrow gravel plain. Each ridge has a general width of about 2 miles but varies in width from 1 mile or less to 4 miles. The combined width of the two ridges and of the travel plain winch separates them is 5 to 7 miles. It is this combined belt that constitutes the Kalamazoo morainic system.

The outer or eastern ridge leads from Prairieville south-southwestward to the Kalamazoo Valley, which it crosses about 5 miles north of the city of Kalamazoo, with an interruption of fully 2 miles. From the west bluff of the river the ridge continues southwestward, passing between Kalamazoo and Brownells station and just west of Oshtemo. It cuts the southeast corner of Van Buren County and passes just west of Marcellus in Cass County and through Cassopolis. It leaves Michigan in the southwest corner of Cass County and extends nearly to the city of South Bend, Ind., where it is interrupted by a broad gravel plain on St. Joseph River.

In Michigan the inner ridge is nearly parallel with the outer. Its inner or western border from Mattawan to Niles is followed by the Michigan Central Railroad. It crosses St. Joseph River near Niles and after doubling back into a bend of the river west of that city goes southward into Indiana and is distinctly traceable as far as the village of Warren, about 6 miles west of South Bend.

Neither of the moraines has been identified with certainty farther south and west. Certain features, however, suggest that the line of continuation is westward past Rolling Prairie to the vicinity of Laporte, beyond which the Kalamazoo is thought to be entirely concealed by the Valparaiso morainic system, unless perchance it is represented in what has been considered the outer portion of that system in northwestern Indiana and northeastern Illinois. One feature which suggests its westward continuation from South Bend toward Laporte is the bowldery, somewhat undulating gravelly district known as Rolling Prairie, which lies east of the station of that name and which stands above the level of the neighboring portion of the Valparaiso system and of the outwash apron connected with that system. Another feature is the great gravel plain which lies north of the Kankakee Marsh in Laporte and Porter counties, Ind., at a level higher than that of the lines of glacial drainage which head in the Valparaiso morainic system and lead through this plain. The plain appears to be older than that connected with the Valparaiso morainic system and to be composed of outwash from an ice border which is largely concealed, as above suggested, by the extension of the Valparaiso system. The altitude near New Carlisle and westward from there to Laporte is 50 to 75 feet above the gravel plains that head in the Valparaiso morainic system.

It is possible that the Kalamazoo system embraces a bowlder-strewn gravel tract known as Sumption Prairie, which lies south of the head of Kankakee River just west of the city of South Bend, but with this exception it seems to lie entirely north of the Kankakee. Aside from basins both Sumption and Rolling prairies have nearly plane surfaces, and both seem to be composed entirely of assorted material capped with a bowlder-strewn loamy deposit a few feet thick. Were it not for the large number of bowlders these tracts would naturally be classed as outwash aprons, and they seem on the whole to be more closely allied to outwash than to moraine.

The great width of the gravel plain on the north side of the Kankakee east of the meridian of Valparaiso may be best explained on the interpretation that the plain was built up by the Lake Michigan lobe in the course of a recession across the area thus covered, and that it buried any morainic features which may have developed during the recession. From the meridian of Valparaiso westward into Illinois, though there is very little outwash between the morainic system and the Kankakee Marsh or between the different members of the morainic system, the bulk of the morainic system is fully as great as the combined bulk of the moraines and gravel plains on the north side of the Kankakee east from Valparaiso and of the combined Kalamazoo and Valparaiso morainic systems in southwestern Michigan. It may, therefore, as above suggested, embrace both the Kalamazoo and the Valparaiso morainic systems, though as yet the two have not been differentiated in that region.

TOPOGRAPHY.

ALTITUDE.

The Kalamazoo morainic system appears to attain its greatest elevation in the immediate vicinity of its junction with the correlative morainic system of the Saginaw lobe near Prairieville, Mich., where its altitude is about 1,050 feet above sea level; at only a few points, however, does it rise above 1,000 feet. The altitude of the outwash apron at Prairieville is nearly if not quite 1,000 feet. The crest of the outer ridge throughout much of its course from Prairieville to the Michigan-Indiana State line is between 900 and 1,000 feet, though for a few miles near the State line it does not quite reach 900 feet. The inner ridge has a crest above 900 feet as far southwest as the vicinity of Dowagiac, but from that city southwestward to the State line it exceeds 800 feet at few points. The

highest points on the bowlder-strewn Rolling Prairie and on the neighboring portions of the gravel plain in Laporte County, Ind., are about 825 feet, but the crest of the morainic system in northwestern Indiana in few places rises above 800 feet and in some places drops to about 700 feet.

RELIEF.

The outer border of the morainic system shows comparatively slight relief, for the gravel plain which follows it for its entire length from Prairieville to South Bend has been built up nearly to the level of its crest. Nor does either morainic ridge show more than slight relief above the gravel plain which lies between them, except in the district from Dowagiac southwest to St. Joseph River, where the inner ridge and the gravel plain drop nearly 100 feet below the crest of the outer ridge. The relief on the inner or western border of the inner ridge is about 200 feet throughout its entire course from Barry County to Dowagiac, the plain west of the ridge being about 750 feet and the ridge nearly 950 feet, but from Dowagiac to Niles the relief on this border is reduced to about 50 feet and it exceeds 75 feet in but few points in the tract west of St. Joseph River.

CHARACTER.

Outer ridge.—Along the entire length of the outer ridge, basins as well as sharp knolls are conspicuous. Many of the knolls stand 50 to 75 feet above the neighboring basins, but only 25 to 50 feet above the bordering outwash apron, below which many basins are sunk 25 feet or more. Many of the basins are occupied by ponds or small lakes, though most of them are either dry or have been sufficiently filled to be largely occupied by vegetation. The gravel plain between the two ridges contains a number of lakes, some of which are one-half mile or more in width and nearly fill the space between the ridges. The great majority, however, are only a few acres in extent and some are but a fraction of an acre. On the west border of the outer ridge for a few miles in the southwest portion in Cass County, Mich., and St. Joseph County, Ind., there is a steep bluff 50 to 100 feet in height which apparently was produced by border drainage along the front of the ice when it had receded a short distance west of the moraine. Elsewhere the inner or west face of the outer ridge carries knolls and basins down to the level of the gravel plain which separates it from the western ridge. In places in the vicinity of the State line the outwash apron extends back into the ridge for a mile or more, and in a number of places basins occupied by small lakes cause slight irregularities, but as a rule the front of the moraine is remarkably regular.

Inner ridge.—The inner or western ridge is much more broken by deep depressions than the outer. These depressions open westward into the inner border district, which, as already stated, is nearly 200 feet lower than the crest of the ridge. The eastern border of the ridge, however, shows only slight irregularity, and the basins are usually only 25 to 35 feet below the level of the gravel plain between the two morainic ridges. The inner ridge has its greatest width immediately northeast of Dowagiac, where narrow gravel plains associated with the moraine lead to the larger gravel plain outside. Immediately south of Decatur the gravel plain for 2 or 3 miles virtually takes the place of the inner ridge, being built to a level nearly as high as the neighboring parts of the moraine.

A conspicuous depression or fosse, one-fourth to one-half mile wide and 20 to 25 feet deep, lies between the inner ridge and the gravel plain immediately east and south of Dowagiac. The gravel plain stands like a bluff on the southeast border of this fosse or depression, but the ridge on the west is very inconspicuous, few of its knolls being more than 10 or 15 feet in height and its crest being scarcely as high as the gravel plain.

The inner ridge in the bend of St. Joseph River west of Niles reaches an altitude only a few feet higher than that of the gravel plain on its south border, but knolls in it are 30 to 40 feet above neighboring sags and basins. It is much broken by basins near the State line and southward to Warren, Ind. Several of the basins contain lakes. The knolls are rather sharp or steep sided throughout this section west of St. Joseph River. On its western or inner face near Buchanan, Mich., a steep bluff 30 feet or more in height has been formed, apparently by border drainage. The ice approached this place very closely while forming the Valparaiso morainic system. Whether the cutting of this bluff occurred immediately on the withdrawal of the ice from the Kalamazoo system or at a later time during the development of the Valparaiso system, has not been clearly worked out.

The topography of Sumption and Rolling prairies, as already indicated, is more like that of the neighboring gravel plains than of the Kalamazoo morainic system. Basins are conspicuous, but knolls and ridges of strong expression are wanting. In places a slight undulation of surface is visible, but it amounts to scarcely 15 feet in vertical range.

One isolated knoll 3 miles east of Laporte in sec. 33, T. 37 N., R. 2 W., rises about 50 feet above the bordering gravel plain and reaches an altitude of 850 feet above sea level. It is separated from Rolling Prairie by the valley of Little Kankakee River.

STRUCTURE OF THE DRIFT.

COMPOSITION.

Throughout the length of both ridges of the Kalamazoo system the drift is mainly assorted material of various grades of coarseness. There is at surface either a loose-textured stony clay or a sandy drift, everywhere carrying a liberal supply of bowlders. On some of the sandiest knolls bowlder piles may be seen in the cultivated fields, and on many of the clayey ones bowlders are so numerous as seriously to hinder cultivation. The general thickness of the capping of bowldery clay is only a few feet. Loose sand and gravel

is reported to underlie wide areas at a depth of less than 10 feet. In places a brown or blue clayey till underlies the looser-textured or more stony surface clay: and in places clayey till is struck at moderate depths beneath sand and gravel in both the morainic system and the outwash tract east of it. But the general prevalence of thick beds of sand and gravel is shown by numerous well records, supplemented by natural exposures near streams and on the edge of the basins of the small lakes.

THICKNESS.

Some wells have reached depths of over 200 feet without penetrating much till or striking bedrock. Some of the deepest wells are found on the border of the Kalamazoo Valley and northward from there into the interlobate spur north of Prairieville. From Kalamazoo south-westward most wells are only 75 to 80 feet deep, though a few are 150 to 160 feet.

In sec. 15, Rutland Township, Barry County, J. Belson bored to a depth of 210 feet from an altitude of about 870 feet without striking rock. Water was found at about 100 feet and the well completed to that depth, the lower part of the boring being through fine sand that did not increase the yield of water.

In sec. 11, Orangeville Township, Barry County, a well made by Mr. Stewart on ground about 975 feet above sea level reached a depth of 150 feet and was entirely through sand and gravel after passing through 10 feet of brown stony clay at the surface. Water was found only in the lower 20 feet. In the vicinity the brown stony surface clay was found to range in thickness from 3 feet up to 16 feet or more, the greatest thickness being in basins. Several wells have reached depths of 150 feet or more without encountering any till except that at the surface.

In sec. 28, Orangeville Township, two wells, starting at an altitude of about 950 feet and having depths of 208 and 196 feet, are reported to have been in sand and gravel after passing through the thin surface bed of brown stony clay.

Near Prairieville some wells 75 to 100 feet in depth have penetrated thin beds of blue clay at about 30 feet from the surface as well as 6 to 8 feet of the brown surface clay. A well in sec. 15, Prairieville Township, penetrated reddish-brown till 10 feet, sand 20 feet, gravel 30 feet.

A well in sec. 1, Cooper Township, Kalamazoo County, on the farm of Mr. Haskins, is 120 feet in depth and shows scarcely 20 feet of clay. A well near by penetrated 40 feet of brown stony till and 43 feet of dry sand, obtaining water in gravel at the bottom. A well in the south part of the same section on the crest of the outer ridge of the Kalamazoo system at an altitude of about 975 feet penetrated alternations of gravel and very stony till throughout its entire depth of 130 feet. Another well 100 rods west, on somewhat lower ground, penetrated reddish-brown till 30 feet, sand 40 feet, reddish brown till 25 to 30 feet, and water-bearing gravel 8 to 10 feet.

On the west side of Kalamazoo River, in southern Cooper Township, several wells on the outer ridge of the Kalamazoo system are 100 to 160 feet in depth and are largely through sand and gravel. A well on the inner ridge in sec. 7, Cooper Township, penetrated 60 feet of sand and gravel and 20 feet of blue clay; it obtains water from the gravel.

In southeastern Alamo Township, Kalamazoo County, on an elevated part of the inner ridge, three wells have penetrated 175 feet largely through sand and gravel and found water only in the lower 50 or 60 feet. The deepest well in the township and perhaps along the whole course of the moraine is that of J. Coshan in sec. 33, which reached a depth of 230 feet on ground about 965 feet above sea level. It penetrated reddish sandy clay and dry sand 20 feet, blue clay 1 foot, white sand 120 feet, bluish water-bearing sand 85 feet, coarse white sand 5 feet. A neighboring well in sec. 28 on the McCall farm, 153 feet deep, penetrated yellowish sand and sandy clay 50 feet, blue clay 10 feet, gray sand 93 feet.

Some wells in the northwestern part of Kalamazoo Township penetrate till to 30 feet or more and then dry gravel to about 100 feet. Several wells are 110 to 120 feet deep. The water has a head about 100 feet below the surface.

On a prominent part of the inner ridge south of Lawton at an altitude of about 930 feet several wells 145 to 160 feet in depth penetrated some till in the lower part as well as a few feet of surface till. A dug well in sec. 8, Porter Township, 100 feet in depth, penetrated a hard clayey till in the lower 35 feet. South of this well, in sec. 17, several tubular wells obtain water at about 60 feet, presumably at the top of this clayey till.

Between Lawton and Dowagiac several wells, both on the inner ridge of the Kalamazoo system and on the gravel plain just outside, have reached depths of 100 feet or more, largely through sand and gravel. Most wells on the outer ridge from the vicinity of Lawton south-westward obtain water at depths of 75 to 80 feet and penetrate but little clayey till. In the low portion of the inner ridge, between Dowagiac and Niles, wells are very largely in sand and gravel, but obtain abundant water at 40 to 50 feet. On the ridge west of Niles many wells reach 80 or 100 feet, some of them penetrating considerable clayey till. As a rule, however, the wells in this section of this moraine and especially in the Indiana portion encounter little besides sand and gravel after penetrating a few feet of surface clay.

On Rolling Prairie many wells are driven to depths of 75 feet or more through sand and gravel, but on Sumption Prairie they obtain water at depths of 50 to 60 feet. In both districts the water table seems to be nearly down to the level of the Kankakee Marsh.

OUTWASH.

DISTRIBUTION IN MICHIGAN.

The outwash district connected with the Kalamazoo morainic system of the Lake Michigan and Saginaw lobes is one of the most extensive in Michigan, for the outwash fills nearly all the space between the Kalamazoo morainic system and neighboring earlier ones. From the reentrant angle between the lobes in southwestern Barry County a gravel plain descends continuously southward across the valley of Kalamazoo River to the St. Joseph Valley, and this constituted the most vigorous line of discharge from the ice border. Outwash aprons lie all along the eastern side of the outer moraine of the Kalamazoo system except for a short interval of 2 or 3 miles in the vicinity of Wakelee, where the moraine approaches an earlier one so closely that only a narrow line of glacial drainage separates them. The width of the outwash tract is measured by the distance between the outer moraine of the Kalamazoo system and the moraine outside; it is about 15 miles throughout much of Kalamazoo County but is only 1 to 5 miles in Cass County, Mich.

SLOPE.

At the head of the reentrant in the vicinity of Prairieville the altitude of the outwash apron is about 1,000 feet, but within a few miles south it drops to about 950 feet. The altitude is nearly 950 feet along much of the western border in Kalamazoo County and remains above 900 feet as far southwest as the vicinity of Cassopolis, but falls to about 800 feet where it joins the gravel plain of St. Joseph Valley north of South Bend. The altitudes just given pertain to the portion of the outwash apron that fits against the moraine; within a mile or two east from the moraine they drop 25 to 30 feet and within a few miles they drop 50 to 75 feet. The water probably ran down the slope eastward and southeastward directly away from the moraine until it met the trunk stream flowing southward from the reentrant angle between the ice lobes. This stream apparently passed east of the site of the city of Kalamazoo and continued southward past Vicksburg, reaching the St. Joseph Valley between Mendon and Three Rivers. The southward slope of the portion of the plain traversed by the trunk stream is indicated by the drainage, streams tributary to the St. Joseph having their sources on the immediate border of the Kalamazoo Valley, and is demonstrated by the following list of elevations:

Elevations on plain leading from reentrant angle.

	Feet.
Prairieville	1,000
Milo	957
Richland	928
North bluff of Kalamazoo	880
South bluff of Kalamazoo	875
Vicksburg	857
Moore Park	841

A definite bluff 15 to 50 feet high on the eastern side of the gravel plain from Kalamazoo River southward to St. Joseph River puts this border in decided contrast to the western border, which grades upward into the moraine. Possibly this bluff was cut by border drainage before the ice had receded to the position of the outer ridge of the Kalamazoo morainic system, for the wide extent of plain over which the waters were free to flow after the ice had receded to that system would seem to leave no necessity for the stream to crowd its eastern bluff. The altitude of the plain for several miles west from this eastern bluff seems also to correspond closely to that of the base of the bluff, so that no reason for crowding is to be found in the slope of the eastern portion of the plain.

BASINS AND CHANNELS.

Basins are very numerous on this outwash tract on the immediate border of the outer ridge of the Kalamazoo morainic system but are scarce out in the midst of the plain; most of them are large, an area of a square mile or more being not uncommon. North of Kalamazoo River they are numerous both on the border of the ridge and in the plain. Their wide distribution is somewhat surprising and seems to indicate that the development of the Kalamazoo system followed closely on the recession of the ice border, there being insufficient time for the large detached masses of ice left in the course of the recession to become entirely melted before the filling of outwash from the Kalamazoo system was completed.

In the vicinity of Kalamazoo several conspicuous valley-like depressions lead from the border of the system eastward to the Kalamazoo Valley. They are about 50 feet below the neighboring parts of the gravel plain and are one-eighth to one-fourth mile in width. At the western or morainal end they head very abruptly, as if cut by a waterfall. Their beds are not graded to a uniform slope but contain basins and other inequalities, which, however, may be no greater than would result from the rush of a strong current of water. One valley is followed by the main line of the Michigan Central Railroad for about 2 miles from the western part of the city of Kalamazoo. Others lie both to the north and to the south. The longest heads in Crooked Lake in sec. 15, Texas Township, about 10 miles southwest of Kalamazoo, leads northeastward, and opens immediately south of the city into a part of the gravel plain corresponding in elevation with its bed. These valley-like depressions are thought to indicate that the discharge from the ice border became localized on certain fines toward the close of the development of the moraine and began to cut instead of fill. While the waters were issuing in shallow sheets all along the edge of the ice they would naturally lay down their earthy burden promptly and would, aggrade the region, but they could hardly do this when they flowed along restricted lines, especially if in considerable volume. This feature is met with in gravel plains elsewhere, though it is by no means common.

FEATURES IN INDIANA.

In the district west of St. Joseph River a gravel plain, with an altitude of 800 feet on its north border near Niles, Mich., slopes slightly to the south or southeast from the edge of the moraine. Between the inner moraine of the Kalamazoo system and the Rolling Prairie bowldery tract

a lower gravel plain known as Terre Coupee Prairie, an outwash from the Valparaiso morainic system, drops from an altitude of about 775 feet where it fits against the moraine to about 700 feet at the edge of the Kankakee Marsh. The Rolling Prairie gravelly tract west of the Terre Coupee Prairie has an altitude of about 850 feet immediately south of New Carlisle but drops to less than 800 feet on its southern border. Between the Rolling Prairie bowldery tract and Laporte another low gravel plain, heading in the Valparaiso morainic system at an altitude of about 780 feet, leads down the Little Kankakee to the Kankakee Marsh. The plain west of it, on which the city of Laporte stands, has an altitude of about 810 feet next to the moraine but drops to 740 feet within about 8 miles southeast of Laporte, and maintains a similar slope toward the Kankakee through its entire breadth in Laporte and eastern Porter counties. This plain is trenched by shallow valleys through which the waters of the Valparaiso system found discharge; one of them is occupied by Mill Creek and another by Crooked Creek,

COMPOSITION OF THE OUTWASH.

Along the border next to the morainic system the outwash material is much coarser than it is at a distance, as it would naturally be if the plain was formed by waters issuing from the ice sheet. Stones several inches in diameter are abundant for about a mile from the moraine, but at greater distances few exceed 3 inches and most of the material is a fine gravel with considerable sandy admixture. Portions of the plain have a capping of 2 or 3 feet of reddish clay, which appears to be more prevalent on the high part of the gravel plain in the reentrant between the Saginaw and Lake Michigan lobes and along the border of the Kalamazoo system in south western Kalamazoo County than it is in the lower and more sandy portions of the plain in central and southern Kalamazoo County. Owing to the clayey character of the soil, portions of the plain in southwestern Kalamazoo County are timbered with beech and maple; yet the clay in few places reaches a depth of 5 feet and it is everywhere underlain by coarse outwash material.

The thickness of the outwash material on the high parts of the gravel plain m western Kalamazoo County and in the reentrant angle in northern Kalamazoo and southwestern Barry counties is only 30 or 40 feet, for many wells enter till within 40 feet of the surface. Till is also exposed in the cuts along the main line of the Michigan Central Railroad west of Kalamazoo to within 40 feet of the level of the gravel plain. East of Kalamazoo in the district south of the valley of Kalamazoo River the gravel is very thin and in places till comes to the surface; this is in the line of the main discharge of water southward from the reentrant angle between the ice lobes. Many of the basins on the gravel plain appear to be as deep as the gravel and to be underlain by clay. On the whole, wells in this outwash tract show a larger amount of till than is found in the moraine. The till seems to be of a clayey texture similar to that east of the gravel plain in southeastern Kalamazoo County.

C. W. Jones's well at Richland, 120 feet in depth, penetrates red clay 3 feet, sand and gravel 40 feet, fine quicksand 3 feet, blue till 70 feet, coarse sand with water 4 feet. D. R. Chandler's well, a mile south of Richland, 152 feet in depth, has blue till in its lower 100 feet. Two other wells in Richland were reported to strike blue till at about 45 feet. A well 45 feet deep in sec. 35, Prairieville Township, Barry County, 3 miles north of Richland, was in blue till in the lower 17 feet. Several wells in the southern part of Richland Township and the northern part of Comstock obtain water at the top of a blue till beneath 50 to 60 feet of outwash material.

At Kalamazoo a boring for gas made in 1887 reached rock at 130 feet. At the waterworks several borings about 120 feet in depth do not reach rock. None of the borings penetrated much till, the greater part of the drift being a fine sandy gravel. All are in the valley of Kalamazoo River at an altitude of about 775 feet, or 150 feet below the high part of the gravel plain west of the city. It is not improbable that the rock surface is as low beneath the gravel plain as in the valley, and if so the drift may be about 300 feet thick in the highest part of the gravel plain.

INTERMORAINIC GRAVEL PLAIN.

The gravel plain between the two ridges of the Kalamazoo morainic system has a general width of about a mile, but in places it is nearly or quite pinched out by protrusions of the inner toward the outer ridge. Its continuity is further broken by basins which fill it almost from side to side. It furnishes, however, a continuous line of glacial drainage from the head of the east branch of Dowagiac River in southeastern Van Buren County, Mich., to the St. Joseph Valley at South Bend, Ind. It descends gradually from about 930 feet near the head of the Dowagiac to 850 feet at Lagrange, Mich, (where the stream leaves the gravel plain to run northwest into the west branch), to about 775 feet east of Niles, and to 750 feet or less to the St. Joseph plain near South Bend.

Some difficulty is found in interpreting the direction of discharge in the part of the gravel plain north of the head of the east branch of Dowagiac River. This northern portion nowhere appears to exceed 950 feet, and in the vicinity of Kalamazoo River is only about 930 feet, or as low as at the head of Dowagiac River. One section of the gravel plain about 14 miles in length, which is cut about midway by the main line of the Michigan Central Railroad, may have found discharge eastward through the eastern ridge at a gap occupied by Crooked Lake and thence northeastward along the valley cut in the gravel plain. This section is shut off from East Dowagiac River on the southwest by a protrusion from the western ridge east of Lawton, and is bordered on the north by a prominent ridge that runs eastward toward Brownells station. Between this last ridge and another projection of the western moraine, which extends southeastward from Alamo to Brownells, is a small gravel plain occupying

about 2 square miles whose altitude is 950 feet and whose line of discharge was probably through narrow sloughs that cross the eastern ridge near Brownells. Near Cooper a gravel plain on the west side of the Kalamazoo, standing about 930 feet above sea level, probably drained southeastward past Kalamazoo. The portion north of Kalamazoo River is likely also to have drained southeastward.

So far as can be ascertained from well records, the gravel plain between the two ridges of the Kalamazoo morainic system is underlain throughout its entire length by very thick deposits of gravel and sand; at least it has so far furnished no evidence of blue till at moderate depths, and it thus contrasts with the outwash apron outside the outer ridge.

KALAMAZOO VALLEY.

In traversing this outwash district from near Galesburg to Kalamazoo, the Kalamazoo Valley leads directly across the line of glacial drainage and then turns northward in a direction opposite to that of the glacial drainage. Under ordinary conditions one would expect the modern drainage to turn southward along the line of the glacial drainage, especially if the district outside the Kalamazoo morainic system was graded up to a southward slope. The size of this portion of the Kalamazoo Valley is also remarkable, being 11/2 to 2 miles wide and about 100 feet deep throughout its course across the outwash district. The valley also is characterized by irregularities not easily referred to drainage erosion, there being recesses in the bluffs and ridgings along the slopes that seem better explained as the result of glacial action. The course of the valley, its great size, and the irregularities of its bluffs suggest the persistence of a mass of stagnant ice along its course during the deposition of the outwash gravel. The subsequent melting of the ice would leave this belt, traversed by the river, lower than the bordering districts and would thus determine the course of drainage. Gull Lake, a few miles northeast of Kalamazoo, is in a large basin which is like that postulated for this section of Kalamazoo River but which did not fall within reach of a river.

A conspicuous feature of the valley is a broad terrace on the east side of the river immediately north of Kalamazoo. It stands about 850 feet above sea level, or a few feet below the level of the gravel plain that extends southward from Kalamazoo River. It seems to have been formed by northward rather than southward drainage. This terrace has no continuation beyond the Kalamazoo morainic system, the country west of the latter being much below its level. In explanation of this high terrace it seems necessary to assume a barrier of some sort below its position. Possibly the morainic accumulations in the valley were sufficient to hold the river up to this level during the development of the terrace. It seems quite as probable, however, that the ice sheet did not entirely melt away until the terrace had been formed. Opposite this terrace the slopes are very irregular, as if ice might have persisted during their development and have thus prevented their smoothing over by the stream. Some evidence of such ice persistence is cited below in the discussion of the Kendall moraine (p. 183).

INNER BORDER.

INTERPRETATION.

The narrow strip between the inner or western morainic ridge of the Kalamazoo system and the Valparaiso morainic system is by no means easy to interpret. The portion from Paw Paw northeastward to the Kalamazoo Valley is especially complex, and it was here that the writer was led astray (see p. 174) in the interpretation presented in Monograph XXXVIII. The outer part of the Valparaiso system from Paw Paw south westward to the State line and beyond is marked by a strong ridge with a regular border, outside of which is a nearly parallel outwash apron that fills much of the space between it and the inner moraine of the Kalamazoo system, from which it is clearly separable.

In the interval from Paw Paw northward to the Kalamazoo Valley in at least two places the Kalamazoo and Valparaiso systems seem to be connected by weak cross ridges, which suggest that the ice border persisted here in its occupancy of the inner face of the Kalamazoo morainic system, while it withdrew several miles from it in the district southwest from Paw Paw and began the development of the strong outer ridge of the Valparaiso system. Aside from these two weak cross ridges there is, in the northeastern township of Van Buren County, a conspicuous drift aggregation which is not easy to correlate with neighboring moraines. There are also conspicuous swampy channels which appear to mark courses of glacial drainage. The intervening tracts not embraced in ridges or in channels are largely sandy and plane surfaced, the only till plain noted being in the southern edge of Allegan County.

An inconspicuous, gently undulating, bowldery strip parts from the Kalamazoo system about 8 miles west of Kalamazoo and passes southwestward to South Fork of Paw Paw River at Paw Paw, nearly opposite the terminus of a strong ridge of the Valparaiso system. Its swells are only 10 to 15 feet high and have very gentle slopes, and its weakness is strikingly in contrast both with the strong moraine of the Kalamazoo system from which it separates and with the bulky moraine of the Valparaiso system with which it may connect at Paw Paw. Bowlders are less numerous on it than on the strong moraines just mentioned. Its soil is sandy and no clayey drift is reported in wells having depths of 40 or 50 feet. On the south side of this undulating strip is a sandy plain, which may perhaps be an outwash apron for it slopes gently southward to the west-flowing portion of the South Fork of Paw Paw River.

Two correlations are possible at the west end of the undulatory strip, one being found in a chain of knolls and short ridges that leads southwestward past Decatur into the northwestern part of Cass County, and the other in a strong morainic ridge of the Valparaiso system that sets

in on the west side of South Fork of Paw Paw River just north of Paw Paw. The most prominent knoll in the first-named chain is about a mile south of Paw Paw and has a height of nearly 150 feet above the village and about 100 feet above the bordering plains. Elsewhere the knolls are only 10 to 20 feet high and are separated by plane tracts of considerable width. Most of the knolls carry bowlders, but the bordering plains are nearly free from them. It is a question whether this weak and fragmentary chain constitutes an ice-border feature. The knolls may have been formed incidentally in the retreat of the ice from the Kalamazoo to the Valparaiso system and not be definitely related to each other nor to the weak ridge that leads into Paw Paw from the inner ridge of the Kalamazoo system.

North of Kalamazoo River the conditions are again simple (as in the district southwest from Paw Paw), a strong morainic ridge of the Valparaiso system with regular border running northward across eastern Allegan County, and a pitted gravel plain to the east filling in much of the space out to the inner ridge of the Kalamazoo system.

KENDALL MORAINE.

A few miles north of Paw Paw lies a prominent ridged belt which rises in an outwash apron east of the main part of the Valparaiso system, in the northeastern part of Van Buren County. The village of Kendall is situated on it and the name Kendall moraine has been applied to it. It is provisionally assigned to the Kalamazoo system though it may prove to be as closely related to the Valparaiso system. Its length is about 9 miles and its width 11/2 to 21/2 miles. The portion north of Kendall is very prominent, knolls 60 to 80 feet in height being present. South of Kendall it is weaker, though a knoll in sec. 31, Pine Grove Township, is 50 feet in height. Ordinarily the knolls in this portion rise only 25 to 30 feet above neighboring sags and basins. Knob and basin topography appears all along the belt, and several of the basins contain small lakes. The surface, especially north of Kendall, is in places very thickly set with bowlders, the largest of which are 8 or 10 feet in diameter. Among them were noted conglomerates of various kinds, including the red jasper conglomerate thought to be derived from the Huronian ledges north of Georgian Bay, a few pieces of gypsum, and numerous limestone fragments derived from Mississippian formations to the north. The drift appears generally to be loose textured though not well assorted. Blue till, if present, lies at considerable depth. A well 202 feet deep on an elevated portion of the moraine in sec. 14, Pine Grove Township, penetrated throughout much of its depth a sandy stony reddish-brown till with a few blue or gray streaks. Considerable blue till was found, however, in a well one-half mile farther east on ground 150 feet lower, which penetrated 8 or 10 feet of gravelly clay and 35 feet of loose gravel and cobble and then went 100 feet into blue till without passing through it.

The Kendall moraine terminates at the northeast in a swamp that is part of a line of glacial drainage which led southwestward from Kalamazoo River to Paw Paw River and which was apparently in operation after the ice had withdrawn. East of this swamp a weak ridge, which may prove to be the continuation of the Kendall moraine, leads northeastward across the northwestern township of Kalamazoo County and connects with the inner moraine of the Kalamazoo system. It is only one-fourth to one-half mile in width and has a gently undulating surface, with a relief on its inner slope of 25 to 50 feet, but with scarcely any relief on its outer slope, the outwash apron being built up nearly to the level of the crest. Bowlders are present on its inner or north slope. Its outwash apron is in harmony with one on the outer border of the Kendall moraine and this perhaps constitutes one of the strongest points in favor of its correlation with that moraine. This correlation of the ridges forms a bridge across the space between the Valparaiso and the Kalamazoo morainic system similar to that near Paw Paw.

WITHDRAWAL OF THE ICE.

Certain features immediately north of the Kendall moraine indicate that the ice withdrew northward from it. Along the slope at the northern end of the prominent part of the moraine, about 125 feet below the crest and about 50 feet above the neighboring swamp, a definite terrace is traceable, running from the middle of the line of secs. 2 and 11, Pine Grove Township, southeastward into sec. 13, a distance of nearly 2 miles, and opening into the outwash apron on the southeast border of the moraine. It seems best explained as having been formed by a line of border drainage running between the ice and the moraine from which the ice had just receded. Within a mile north of this terrace a till plain sets in and a similar till plain is found north of the weak ridge east of the swamp, both of which fit in naturally as ground moraine connected with the terminal moraines just discussed.

On this interpretation the ice held its position along the inner edge of the Kalamazoo morainic system north of Kalamazoo River while forming the Kendall moraine and the weak ridge that apparently connects it with the Kalamazoo system. Features immediately southeast of Plainwell suggest that the ice may have protruded into the Kalamazoo Valley at the time the Kendall moraine was forming. The weak ridge which leads in from the west seems to wrap around the base of the prominent part of the Kalamazoo system south of Plainwell and to extend southeastward through secs. 5 and 9, Cooper Township, along the west bluff of Kalamazoo River. Possibly this protrusion of the ice into the Kalamazoo Valley may have held the river at the level of the broad 850-foot terrace near Kalamazoo. If so, the stream is likely to have found escape along the ice edge, between the weak ridge just mentioned and the prominent inner ridge of the Kalamazoo system south of Plainwell, into the low country west of the Kalamazoo system.

GLACIAL DRAINAGE.

Considerable complexity marks the glacial drainage. The swamps which occupy the beds of the old lines of

drainage can not be connected into a single drainage system. A conspicuous swamp heading just south of Paw Paw is 755 to 760 feet in altitude at its north end and slopes southwestward to about 720 feet at its south end west of Dowagiac, where its bed is expanded into a plain that was apparently occupied by a lake termed Lake Dowagiac (see Ann Arbor folio), which discharged into the Kankakee at South Bend, Ind. This swamp probably was functional as a line of glacial drainage at the time when the ice occupied the weak ridge that leads eastward from Paw Paw to the Kalamazoo morainic system and continued functional until the ice had receded sufficiently to permit the glacial waters to discharge down the Paw Paw Valley.

A second conspicuous swamp heads northeast of the prominent part of the Kendall moraine and leads southwestward down Paw Paw River. This swamp has an altitude of about 725 feet at the divide between Kalamazoo and Paw Paw rivers, east of Kendall, and falls to about 700 feet at the junction of the two forks of Paw Paw River north of the village of Paw Paw. It has cut into the outwash apron bordering the Kendall moraine to a depth of 25 feet or more, indicating that it is somewhat the younger. Evidently the ice must have receded to the north side of Paw Paw River as far down as the edge of Berrien County, or nearly to its mouth, before glacial drainage could have made use of the Paw Paw Valley, and this apparently was considerably later than the time of the formation of the Kendall moraine.

A third swampy belt, north of Kalamazoo River, is followed by Gun River from Gun Lake down to the Kalamazoo. Its altitude is scarcely 725 feet where it is crossed by the Grand Rapids & Indiana Railway north of Plainwell, or a little less than at the northern end of the swamp that leads from the Kalamazoo southward to the Paw Paw drainage. The difference, however, is very slight and it is not improbable that the whole excess is due to peaty accumulations on the divide between Kalamazoo and Paw Paw rivers, in which case the drainage from the Gun River channel may have been continued into the Paw Paw channel.

LAKE MICHIGAN-SAGINAW INTERLOBATE TRACT.

DISTRIBUTION.

The junction between the Lake Michigan and Saginaw lobes during the formation of the Kalamazoo morainic system was in western Barry County, a few miles southwest of Hastings. In the course of the development of the moraines the junction worked northward in a somewhat zigzag course, being for a time in the southern edge of Kent County about 12 miles south of Grand Rapids, later near the site of the city of Grand Rapids, and still later a few miles south of Big Rapids. From Big Rapids north to Cadillac a very massive morainic accumulation was formed, covering the western half of Mecosta County, the eastern part of Newaygo and Lake counties, a large part of Osceola County, and a few miles of southeastern Wexford and southwestern Missaukee counties. This accumulation is more than 50 miles in length and 25 miles in breadth and is by far the most prominent morainic development in the southern peninsula.

TOPOGRAPHY.

ALTITUDE.

Near the northern end of the interlobate tract, about 10 miles southeast of Cadillac, is the highest point in the southern peninsula of Michigan, the precise location being in sec. 12, Sherman Township, Osceola County, and the altitude a little more than 1,700 feet above sea level. A tract of only a few square miles of this moraine, mainly in the area just referred to, rises above the 1,500-foot contour; about 50 square miles in the same region rises above the 1,400-foot contour; and but little more than 100 square miles rises above the 1,300-foot contour. A considerable portion of the massive belt from Big Rapids northward rises above the 1,000-foot contour, but from Big Rapids southward only the crests of the ridges and a few prominent points reach that altitude. The altitude in the vicinity of Grand Rapids is little more than 800 feet on the crests of the morainic ridges and is only about 700 feet on the lower land between the ridges. At the junction of the outer moraine of the Kalamazoo system and its correlative moraine of the Saginaw lobe southwest of Hastings an altitude of about 1,050 feet is attained. The range in altitude along the line of this interlobate tract is thus about 1,000 feet—from 700 feet up to 1,700 feet above sea level. From this interlobate tract there is a general westward descent to the Lake Michigan basin and a general eastward descent to the Saginaw basin. (See Pl. VII.)

RELIEF.

The relief of the massive moraine above the border districts is more conspicuous from Mecosta County northward than it is southward. In eastern Newaygo and Lake counties it amounts to about 300 feet above the plains on the west, and in northern Osceola County it is about as much above the plain around Cadillac. On the eastern border north of Muskegon River it is 300 to 500 feet, but south from that stream it scarcely exceeds 100 feet. From the vicinity of Big Rapids southward it is as much as 100 feet in only the most prominent parts of the morainic system. In the southern part of the system it is most conspicuous in western Barry County near the junction of the Kalamazoo system of the Lake Michigan lobe with the same system of the Saginaw lobe, where the crests of the highest ridges stand about 300 feet above the low plain to the west traversed by Gun River.

CHARACTER.

The interlobate tract is generally of a pronounced knob and basin type of topography, but it includes gentle swell and sag areas of considerable size. One of the most extensive of these lies south of Grand Rapids, where

only a few sharp knolls appear throughout an area of perhaps 100 square miles. The portion of the Kalamazoo morainic system between Grand and Muskegon rivers in northern Kent and western Montcalm counties carries only a few prominent ridges and has few knolls that exceed 50 feet in height. A considerable part of the massive moraine in Newaygo, Mecosta, Lake, Osceola, Wexford and Missaukee counties has a very irregular surface with sharp knolls 50 to 100 feet in height, among which are numerous basins. The highest part of the moraine, where an altitude of 1,700 feet above sea level is attained, consists not of sharp knobs but of a massive accumulation covering several square miles and rising like a great dome above the surrounding moraine. The greater part of it has already been brought under cultivation while neighboring lower districts with more broken surface still remain uncultivated. In Barry County, especially southwest of Hastings, the Kalamazoo morainic system is characterized by larger lakes than are commonly found elsewhere along the interlobate tract. Indeed, lakes are not so conspicuous in this interlobate tract as in the one between the Saginaw and Huron-Erie lobes. Small lakes and marshy depressions are, however, very common all through it.

The interlobate tract includes several small gravel plains which were developed as outwash from one or both of the ice lobes. They are in places thickly set with basins—conspicuously so as a rule at the border between the gravel plains and the associated moraines. The distribution of the basins and the slope of the plains indicate the source of the outwash, which in some places appears to have been the product of but one of the lobes. For instance, a plain north of Grand Rapids on the east side of Grand River has conspicuous basins on its eastern edge next to the moraine of the Saginaw lobe, and it slopes from that moraine toward Grand River. The northeastern portion of a plain in northwestern Montcalm County and neighboring parts of Mecosta and Newaygo counties rises toward the moraine of the Saginaw lobe, but a narrow southern extension rises toward the west to a moraine of the Lake Michigan lobe. The plain in northeastern Allegan County and the large plain outside the Kalamazoo morainic system in southern Barry and neighboring parts of Kalamazoo counties both seem to have been joint products of the Saginaw and Lake Michigan lobes, for they slope away from a moraine of each lobe.

On the whole, gravel plains are rather poorly developed in this interlobate tract. The most conspicuous is one that covers perhaps 100 square miles in northwestern Montcalm and neighboring portions of Mecosta and Newaygo counties. Another in eastern Allegan County is of similar size if the entire outwash from the Lake Michigan lobe in the district north of Kalamazoo River is included. The gravel plains in the vicinity of Grand Rapids and northward from there into northern Kent County are all very small, amounting altogether to scarcely 100 square miles.

In the very massive part of the interlobate moraine from southern Mecosta County northward to Cadillac, the only gravel plains are along the valleys of the principal streams, Muskegon and Hersey rivers. The one on the Muskegon is largely a line of glacial drainage from the headwaters of Muskegon River and is therefore to but slight extent referable to drainage attending the development of the interlobate tract. The plain along Hersey River appears to be an outwash from the Lake Michigan side of the interlobate moraine. This massive part of the moraine is made up of strips of gravelly or sandy moraine alternating with strips of somewhat clayey moraine. These gravelly and sandy strips are thought to correspond in a certain degree to outwash aprons, but owing to the nearly complete coalescence of the ice lobes the gravel and sand was prevented from being spread out in a plain and has a topography similar to the remainder of the moraine.

The relation and trend of the morainic ridges of the Saginaw and Lake Michigan lobes in the interlobate district indicate the northward shift of the reentrant angle. The moraines of the Saginaw lobe lead up to the line of junction from the southeast, and those of the Lake Michigan lobe lead up to it from the southwest or south, and the outwash aprons or gravel plains just mentioned occur at the junction. The reentrant appears to have worked back northward to the southwestern part of Mecosta County while the massive moraine which extends northward from there to Cadillac was yet in process of formation. From this massive moraine the lobes probably shrunk away, the Saginaw to the east and the Lake Michigan to the west, uncovering it simultaneously along nearly the entire length, instead of retreating along it from south to north.

STRUCTURE OF THE DRIFT.

THICKNESS.

The rock surface beneath this interlobate tract probably in no place greatly exceeds 700 feet above sea level and may in places drop to as low as 200 feet above the sea. The drift surface ranges from 700 to 1,700 feet. The thickness of the drift may, therefore, in places exceed 1,000 feet and it probably averages more than 500 feet. Yet there is a small area in the vicinity of Grand Rapids where the rock is near the surface and where all but one of the borings that have reached rock are located. The one exception is the Red Cross mineral well near Big Rapids, which penetrated about 450 feet of drift and struck rock at 525 feet above sea level. A boring made by the Grand Rapids & Indiana Railway at Big Rapids reached a depth of 245 feet (670 feet above sea level) without striking rock. A waterworks boring at Big Rapids 200 feet in depth terminated at an altitude 680 feet above sea level without striking rock. At Reed City a boring at the waterworks and another at the electric-light plant, each about 275 feet in depth, terminated at 750 feet above sea level without reaching rock. A well only a mile from the highest point in the southern peninsula, on the farm of Albert Miller, sec. 11, T. 20 N., R. 9 W., at an

altitude of 1,580 feet, was sunk 337 feet without striking rock.

No means have as yet been found for determining how much of this great mass of drift is referable to the Wisconsin and how much to preceding stages of glaciation. The convergence of the ice lobes and the comparatively small removal by glacial drainage favored a large accumulation of drift, and the amount deposited at the last ice invasion may be as great as the relief of the ridges, or an average of about 300 feet.

COMPOSITION.

The surface portion of the drift, particularly in the northern part of the morainic tract, presents interesting alternations of gravelly or sandy drift with a somewhat clayey drift. In the southern part the sharp ridges and knolls are largely of gravel and sand and the gently undulating tracts are chiefly of till. Till is in some places only a thin veneer over thick deposits of gravel and sand; this is especially noticeable in the district southwest of Hastings, where wells have been sunk to 150 to 200 feet entirely through sand and gravel except 10 to 20 feet of clayey material at the surface. The variations in structure can perhaps be best described from south to north, in the direction of ice retreat and the order of development of the morainic tract.

In Barry County, southwest of Hastings in the vicinity of the "junction of the outer moraine of the Kalamazoo system and its correlative of the Saginaw lobe, the moraine is chiefly of sand and gravel with a thin veneer of bowldery till. In places, especially east of Gun Lake and south of the bend of Thornapple River below Hastings, the surface is sandy. From Hastings directly northwestward to Grand Rapids the drift appears to be entirely from the Saginaw lobe and is chiefly clayey till. Some surface sand appears along the borders of Thornapple River. In the bend of the river north of Grand Rapids sand and gravel lie along the immediate edge of the Valley, but a stiff clayey till is found farther back. The moraine on the north side of Grand River west of Grand Rapids was produced by the Lake Michigan lobe and is also largely of till -with more or less sand near the edge of the Grand and Rouge river valleys. In the northern part of Kent County, from the Grand Rapids & Indiana Railway west to Rouge River and also for 2 to 4 miles east of the railroad, the drift is largely gravelly and sandy, but farther east it is prevailingly clayey till.

Considerable clayey till occurs in the part of Montcalm County south of Tamarack Creek in a district covered by the Saginaw lobe. Gravelly drift appears, however, over an area of perhaps 50 square miles on the west side of Flat River in northern Montcalm County, much of which is sharply ridged. The smoother tracts to the north are about equally divided between clayey and sandy drift.

A prominent ridge formed by the Lake Michigan lobe in the southeast part of Newaygo County has clayey till on its western slope but is gravelly and sandy on its crest and eastern slope. The morainic system in eastern Newaygo County north of Muskegon River is very largely of sandy and gravelly drift, but is of clayey drift over about 10 square miles in the northeast corner of the county in the eastern part of Barton Township. This clayey drift extends eastward to the Muskegon Valley in Mecosta County north of Big Rapids, and northward in a strip several miles wide along the line of Lake and Osceola counties to the vicinity of Leroy in western Osceola County. West of it in Lake and Newaygo counties there is an elevated range of gravelly and sandy hills.

In Mecosta County the district between the Muskegon and Little Muskegon valleys carries a succession of clayey and sandy strips trending nearly east to west. In the southwestern part of the county a clay strip about 5 miles wide running westward from Altona past Borland lies immediately back of the large outwash apron developed by the Saginaw lobe and is apparently the product of the Saginaw lobe. North of this clayey tract, in the northern half of Austin Township and south of the line from Byers to Rodney, a very sandy morainic tract 4 to 6 miles wide stands higher than the till tracts on either side. Immediately southeast of Big Rapids a till tract has its northern border near the line of the Pere Marquette Railroad between Big Rapids and Rodney. North of this is another sandy tract that has its northeastern limits near Chippewa Lake and its southeastern limits near Rodney; it is less elevated than the sandy tract in Austin Township and in places has the general features of a pitted gravel plain. These sandy tracts have very few surface bowlders compared with the number on the bordering till tracts. A large section of the moraine lying along a line running from Big Rapids past the north end of Chippewa Lake to Barryton and extending on the north to Muskegon River has a preponderance of till but includes small areas of sandy and gravelly drift.

North of Muskegon River, in central Osceola County, an area of about 75 to 100 square miles of very sandy and elevated moraine is entirely surrounded by lower tracts with a somewhat clayey drift. In the northern part of Osceola County, on the highest land of the southern peninsula, considerable till is present, the sandiest tracts being in the relatively low districts in the northwestern and northeastern parts of the county.

Along the southern edge of the southeastern township of Wexford County and in much of the southwestern township of Missaukee County clayey drift is present, but in the district immediately east of Cadillac at the extreme northern point of the interlobate moraine an area of several square miles is very sandy.

BOWLDERS.

Bowlders, which are almost or wholly lacking on other sandy portions of the moraine, thickly strew the sandy district in central Osceola County. They are less numerous on the sandy strip in eastern Lake and eastern Newaygo counties than they are on the clayey tracts to the east, but they are by no means rare in either place. Except on the small sandy areas they average

several thousand to the square mile on the prominent part of the morainic system from Cadillac southward to southern Mecosta County. In the southern part they are generally concentrated in the vicinity of the sharper ridges and knolls and are relatively scarce on the gently undulating tracts, being most prevalent in western Barry County and especially in the district southwest of Hastings, where they are almost as numerous as in the prominent northern portion.

GLACIAL DRAINAGE.

The drainage from the reentrant between the Lake Michigan and Saginaw lobes at the junction of the outer moraine of the Kalamazoo system and its correlative moraine in the Saginaw lobe was southward from southern Barry County across central Kalamazoo County to St. Joseph River below Centerville. It passed directly across the present course of Kalamazoo River east of Kalamazoo. Its gravel plain has an altitude of nearly 1,000 feet at its head near Prairieville in Barry County, but descends to less than 900 feet at the bluff of Kalamazoo River, to about 800 feet at the place where it enters Indiana a few miles southwest of Centerville, and to about 720 feet at the bend of St. Joseph River near South Bend, Ind. From South Bend the discharge was down the Kankakee to the Illinois and thence to the Mississippi and the Gulf of Mexico.

From the reentrant between the two ice lobes in northeastern Allegan County the drainage was southward along the Gun River valley to the Kalamazoo and thence either to South Bend through the low tract west of the Kalamazoo morainic system or down the Paw Paw Valley to a glacial lake held in front of the ice near the mouths of Paw Paw and St. Joseph rivers. It is probable that the former course was in operation until after the ice had withdrawn from this gravel plain, and that the latter course was utilized by the later glacial drainage that came down the Thornapple Valley.

From the reentrant between the two ice lobes at the bend of Grand River north of Grand Rapids the drainage was southward along a well-defined valley that led past Ross and on through northern Allegan County. It appears to have continued for a time southward to the Kalamazoo Valley at Allegan, but on the withdrawal of the Lake Michigan ice lobe from a moraine north of Allegan it shifted to the west side of the moraine and made its way southward along the edge of the receding ice to the head of Lake Michigan and thence to Desplaines, Illinois, and Mississippi rivers.

From the reentrant angle a few miles south of Big Rapids the drainage appears to have passed southward from the Muskegon Valley to the head of the Rouge River valley and thence to Grand River, beyond which it probably followed the course past Ross previously outlined. As the ice lobes separated this line of glacial drainage extended up the Muskegon Valley as far probably as the vicinity of Hersey. There appears also to have been some drainage from the Lake Michigan lobe down Hersey River to Hersey. The portion of the Muskegon above Hersey served as a line of glacial drainage until the ice sheet had receded east of the headwaters of the river, or until later than the development of the morainic system under discussion.

KALAMAZOO MORAINIC SYSTEM OF THE SAGINAW LOBE.

COURSE AND DISTRIBUTION.

The Kalamazoo morainic system, of the Saginaw lobe connects at the west with the Kalamazoo morainic system of the Lake Michigan lobe and appears to be its full correlative. Its outer or southern border is definitely limited by a large outwash apron along much of its course, the only exception being a few miles in western Jackson County, where it terminates in a hilly district through which lines of border drainage were developed. The border trends southeastward from Prairieville in southwestern Barry County across the northern part of Calhoun County into western Jackson County. Near the village of Spring Arbor, about 10 miles west of Jackson, it swings to north of east and runs past Jackson to the edge of Washtenaw County, where it connects with the correlative system (Mississinawa morainic system) of the Huron-Erie lobe. The belt is only about 2 miles wide east of Jackson and for a few miles in the vicinity of Marshall, but elsewhere is 6 to 12 miles wide. At its western end it occupies the entire space between Prairieville and Hastings, its north border in the vicinity of Hastings being Thornapple River valley. It is also of great breadth along the east side of Battle Creek, where a spur extends from it northward nearly to Charlotte. In northwestern Jackson County it is separable into three more or less distinct moraines with intervening narrow strips of gravel plain and border drainage. The inner members of the system, however, die out or become very diffuse east of Grand River.

TOPOGRAPHY.

ALTITUDE.

The relief of this morainic belt above the gravel plain on its outer border is but slight, in most places being less than 30 feet and in few more than 50 feet. The gravel plain, however, is elevated, the altitude in the reentrant angle between the Lake Michigan and Saginaw lobes being nearly 1,000 feet and in that between the Saginaw and Huron-Erie lobes more than 1,000 feet above sea level. The border drainage lines leading westward from Jackson are also between 950 and 1,000 feet above sea level. The lowest part of the border is in the vicinity of Battle Creek, where the gravel plain is scarcely 900 feet and the moraine only about 950 feet. The moraine is traversed by several streams, such as Wabascon, Wanandager, and Battle creeks, hut these streams run in deep depressions whose borders are higher than the plains in which the streams have their sources.

RELIEF.

The inner border relief is inconspicuous in Eaton and Barry counties, there being in places a gradual transition from the moraine to the bordering till plains. In northeastern Calhoun County a large swamp lies immediately north of the moraine, but its altitude is only 25 to 50 feet below the bordering morainic ridges. The moraine leading northeastward from Jackson rises nearly 150 feet above the Portage swamp which lies on its north border, this being the most prominent part of the entire morainic system. The relief of the ridges in northwestern Jackson County above the depressions occupied by Grand River and Sandstone Creek in places exceeds 100 feet.

CHARACTER.

In western Barry County, where this morainic belt connects with the Kalamazoo system, knob and basin topography prevails, sharp knobs rising 50 to 100 feet above the surface of the numerous lakes inclosed in basins. Southeastward the lakes become more scattered, but knob and basin topography continues along much of the moraine. Not a few of the knobs rise abruptly 50 to 60 feet, but these are interspersed with many low knolls 20 feet or less in height. In the vicinity of the Battle Creek valley marshy tracts of considerable extent are inclosed by sharp sandy knolls, some of which are 60 feet or more in height. Wanandager Creek crosses the moraine through a swampy plain. Knolls 60 feet or more in height are numerous along the east side of Battle Creek as far north as Olivet. In eastern Calhoun and western Jackson counties a few knolls are 50 or 60 feet high, but the great majority reach only 15 or 20 feet. Swampy east-west valleys that traverse the district are thought to have carried the border drainage to Kalamazoo River. Some of them are occupied by Rice Creek and its tributaries, but others are not traversed by streams at the present day. Narrow strips of nearly plane gravelly land alternate with the morainic strips. Many of the plains are pitted and appear to be outwash aprons formed on the front of the receding ice border. Near the mouth of Sandstone Creek, in northwestern Jackson County, knolls fronting on the Grand River valley rise abruptly 80 to 100 feet above the valley bottom, but farther south the moraine is smoother. To the east, in Rives Township, knolls 40 to 60 feet in height rise abruptly from swampy tracts, and an esker leads southward from Rives Junction nearly to the city of Jackson.

The sharp morainic belt leading from Jackson eastward along the south side of Portage Swamp contains knobs 75 to 100 feet or more in height which stand near the south border of the range. An undulating strip a mile or more in width extends from the base of these knobs down to the border of the swamp.

North of the Portage Swamp knolls are found only in clusters or small detached areas surrounded by nearly plane tracts of sandy drift which rise northward into a later morainic system, the Charlotte. These are probably correlatives of better-defined morainic belts in northwestern Jackson County.

STRUCTURE OF THE DRIFT.

COMPOSITION.

On the whole, the drift of this morainic system is of rather sandy texture. It tends to grade into clayey till toward the inner or north border, especially in Barry and Eaton counties. In Calhoun and Jackson counties, where the underlying rock is sandstone, the till is generally sandy.

BOWLDERS.

Bowlders are found in great numbers along much of the southern edge of the moraine from Barry County to Washtenaw County. They are least conspicuous in the vicinity of the Battle Creek valley, where the drift is exceptionally sandy. Bowlders are also found some distance back from the border in belts, many of which are traceable for several miles. In central and western Jackson County, as in districts to the south where sandstone hills are present, small surface bowlders are remarkably numerous—so numerous, indeed, that fences miles in length are built of them. Many of them are only a foot or two in diameter. The great majority are of granitic rock and are rounded by exfoliation. The bowlders appear to be much more numerous on the surface than beneath it; their numbers are rarely troublesome in well borings even where the surface is thickly strewn.

In the vicinity of the reentrant angle in Barry County bowlder belts trend north-northeast and south-southwest, the direction corresponding pretty closely to that of the ridges of the Lake Michigan part of the Kalamazoo system. East of this reentrant angle, however, the bowlder belts trend north-northwest and east-southeast, conforming to the direction of the Saginaw part of the Kalamazoo system.

THICKNESS.

In the vicinity of the reentrant angle in Barry County, between the outer moraine of the Kalamazoo system and its correlative in the Saginaw lobe, records were obtained of several wells 80 to 150 feet in depth, all of which terminate in drift. The bowldery surface clay is commonly but 5 to 10 feet thick and is underlain to a considerable depth by sand. East of the reentrant angle the lower parts of wells contain till, alternating with thin beds of sand and gravel. There are, however, considerable areas in which very little till occurs except in the thin sheet at the surface. Many wells reach depths of 80 to 90 feet. Some penetrate a blue quicksand, generally beneath blue till, but in most of them the sand is gray or yellowish and is moderately coarse.

In Calhoun County west of Battle Creek records of wells 100 to 125 feet deep show a large amount of assorted material, some of which is described as reddish sand

and some as gravel and sand. In sec. 16, Penfield Township, two wells, 110 and 125 feet deep, stand on a very prominent portion of the moraine 80 to 100 feet above the valley of Battle Creek. The 110-foot well has the following record:

Record of well in Penfield Township, Calhoun County, Mich.

	Feet.
Bowlder clay, yellow	15
Bowlder clay, blue-gray	4
Cobble, gravel, and sand	50
Sand, reddish	35
Gravel and water	6
	110

In much of Convis Township, which lies east of Battle Creek valley, the drift is very sandy, but in the southwestern portion the soil is heavier and the wells encounter considerable bowlder clay, though even here some wells are largely in gravel and sand. In the vicinity of the swamp in Lee Township wells are reported to penetrate a slightly pebbly blue-gray clay. In northern Marengo Township wells penetrate yellowish till for 8 to 15 feet and then commonly enter dry sand, though some find bluish till. In the northeastern townships of Calhoun County the wells indicate that the drift is mainly sand and gravel; some of the wells pass into rock at depths of 50 feet or less.

The spur which runs northward into Eaton County along the east side of Battle Creek contains considerable clayey till, but carries gravel knolls and a short esker. Some of the wells are in sand or gravel in their lower and clayey till in their upper part. Native copper is reported from the drift about Olivet. Knolls in the village of Olivet are gravelly, but some of them are shown by wells to contain a blue till at about the level of their base.

In northwestern Jackson County sandstone is entered in most wells at depths of less than 50 feet though in some the drift goes down about 100 feet. It is commonly sandy or loose textured throughout but is not definitely assorted, the sand being derived from the local sandstone.

The strong moraine leading eastward from Jackson is gravelly and so far as ascertained contains but little clayey material. Many of its knolls show abrupt changes from sand to gravel and cobble. North of the Portage marsh sand in places forms but a thin cover over the till; wells are obtained at slight depth (some after penetrating only 5 or 6 feet of till), and the extent and depth of the till is not known.

INNER BORDER.

GENERAL CHARACTER.

Only narrow strips of plain lie between the Kalamazoo and Charlotte morainic systems and between the constituent ridges of the Kalamazoo system. The strip between Marshall and Charlotte is the widest, attaining a width of 15 miles; the ordinary width is less than 10 miles. The strip between the outer and second ridges in Jackson County is nearly 6 miles wide where widest. Along Portage River it is largely a sandy swamp, but west of Grand River it is a cultivable till plain, traversed by a sharp esker ridge. A small area of cultivable sandy till lies north of Portage River near its mouth. In western Jackson and eastern Calhoun counties the narrow strips between the ridges of the Kalamazoo morainic system are sandy or gravelly and in part swampy.

The strip between the Kalamazoo and Charlotte morainic systems in Barry and Eaton counties is gently undulating till of high fertility. In Calhoun County it is largely swampy, including a swamp covering much of Lee Township. In southern Ingham County it includes sand plains, large marshes, undulating till tracts, and a few sharp gravel ridges of esker type. In places it so grades into the bordering moraine as to be difficult to delimit.

The drift is of moderate thickness, 30 to 60 feet or less (aside from preglacial valleys), in much of the district east of Battle Creek. West of that stream it is much thicker because of the lower altitude of the rock surface, and in eastern Barry County it probably exceeds 150 feet.

One occurrence of buried soil between drift sheets is known. A well on the farm of Mr. Diebolt in the southwest part of sec. 25, T. 2 N., R. 6 W., in western Eaton County, penetrated a black muck under till at 35 to 40 feet from the surface. Below the muck was a sand that yielded water. Neighboring wells go down 75 to 100 feet and in one place 190 feet without reaching rock, so it is probable that this black muck is between the Wisconsin and Illinoian till sheets.

The most striking features of the tracts between the two morainic systems are the eskers which occur both as long chains of gravel ridges and as isolated short ridges.

RIVES ESKER CHAIN.

The Rives chain of ridges is one of several that extend from the low plains near Lansing up through the strong moraines to the south. Several of the eskers do not reach to the Kalamazoo morainic system but terminate in the next later or Charlotte system. The Rives esker system sets in at the south border of the Charlotte system and leads southward in disjointed sections for about 16 miles, nearly to Jackson. Its southern portion, from Rives Junction southward, was probably formed while the ice border was still holding its position at the moraine in Jackson. Another section, which lies entirely north of Grand River, is likely to have been formed after the ice border had shrunk back nearly to the line of Ingham and Jackson counties. The third or northern section, which lies in the outer edge of the Charlotte morainic system, may prove to be as young as that morainic system. The fact that these esker ridges lie end to end in a nearly continuous esker trough is taken to indicate that they have at least been formed in close succession by an essentially continuous subglacial stream. It may seem remarkable that a subglacial stream should have maintained its track during so great a recession of the ice border, but this is only one of several esker systems in southeastern Michigan which seem to require this interpretation.

The southern section leads a little east of south from Rives Junction, nearly to Jackson, a distance of about 7 miles. It lies in a swampy depression, one-eighth to one-fourth mile in width, which is utilized by the Michigan Central Railroad and the Jackson-Lansing Electric Line. The greater part of the esker is in view from the railway trains. Except for a mile or so at the north end, which is strongly morainic, the district bordering the esker is a gently undulating till plain, in which the esker terminates at the south without any gravel fan or delta. However, a number of kames within a mile south of it in the northwestern part of Jackson may perhaps be the product of the same stream which produced the esker. The height of the esker ranges from 5 feet up to nearly 50 feet. Its highest part was in the village of Rives Junction, but this has been removed for railway ballast. The esker seems to contain a large amount of gravel suitable for railway ballast, but pits on its eastern slope near Rives Junction contain also beds of sand.

The middle section has its southern terminus directly across the valley of Grand River about 11/2 miles northwest of Rives Junction and its northern end about 4 miles to the north in sec. 24, Onondaga Township, Ingham County. It lies in sees. 24 and 25 and the north part of sec. 36, in a swampy depression which extends a mile or more farther north than its north end. From the southeast part of sec. 36 southward to Grand River the esker lies on the slope of a small north tributary of Grand River and is less continuous than in the swampy channel to the north. Much of it is only 10 or 15 feet high, but in the middle part of its course it attains a height of about 40 feet. At the southern end it divides into a network of ridges which incloses basins. Opposite its south end, on the south side of Grand River, a gravelly plain containing basins and standing 15 to 30 feet above the stream may prove to be a delta or fan connected with it.

The third or northern section is in a swampy depression in the headwaters of Willow Creek in the northeast part of Onondaga Township. The swamp extends from the north line of the township southward along the border of secs. 1 and 2, 11, and 12, into sec. 13. It is separated from the swampy channel containing the middle section of the esker by an undulating tract of sandy drift about half a mile wide. The esker is a low ridge, commonly but 15 to 20 feet high, which winds back and forth across the line of secs. 11 and 12 in a general southward course. A short parallel esker ridge lies in the southeast part of sec. 11. Near the southern ends of these ridges lies a group of sharp kames 40 or 50 feet high and beyond these the gently undulating tract just mentioned. The trough in which this esker lies is in the outer part of the Charlotte morainic system and is bordered by a very bowldery, knob and basin morainic tract. The middle section of the esker, on the other hand, has its entire course through a gently undulating tract such as separates the moraines of this region.

The excavations in the Rives esker throughout its entire length show a large preponderance of material of local derivation, Carboniferous sandstone being conspicuous and forming a great majority of the cobbles and coarser stones. This is interesting in view of the fact that the surface bowlders of the border districts are very largely granitic rocks of distant derivation. The stream which formed the esker appears therefore to have derived its material from very near the base of the ice sheet. A similar condition has been noted in many other eskers in Michigan and neighboring States.

The swampy depression along the line of the esker was probably not excavated in a single tunnel, for in many places it is one-fourth mile or more in width. It is more probable that the subglacial stream shifted back and forth, carrying away the englacial material which would otherwise have gone to fill this depression. The depressions or esker troughs antedate the esker ridges, the ridges being the last feature produced before the disappearance of the ice.

The kames associated with parts of the esker seem likely to have been closely connected with it in origin and to have been developed by the concentration of material in openings in the ice. The material in the kames, like that in the eskers, is largely local, indicating that it came from the basal portion of the ice sheet.

WALTON ESKER CHAIN.

The Walton esker chain lies in Walton Township, Eaton County, a few miles southwest of Charlotte, along the borders of the Battle Creek valley. Its northern end is in secs. 2 and 3, Walton Township, just south of a swamp which bears westward from Battle Creek toward Olivet station and which seems to have been a line of glacial drainage that comes back to the Battle Creek valley south of the station. The present valley of the creek is very narrow and seems hardly adequate to have carried the glacial drainage.

A complex network of ridges 5 to 15 feet high, among which are basins and level gravelly tracts, forms the head or northern end of the esker in secs. 2, 3, 10, and 11. The ridges lead into sec. 15, to what seems to be an esker delta or fan-shaped plain that stands about 40 feet above the creek, the whole constituting the northern and probably the youngest section of the esker chain. The delta plain lies south of the Battle Creek valley and extends nearly a mile west from the intersection of Big and Battle creeks; it contains basins 20 feet deep but otherwise is nearly level.

The second section of the chain consists of a sharp gravel ridge 30 to 40 feet high which leads south from the southwest part of sec. 15 and which is bordered on each side by narrow swampy depressions. This leads into a fan-shaped expansion, with nearly level surface, which lies about 2 miles south, in the east part of sec. 27, and which constitutes the southern end of the section. The ridge has been opened for gravel in a few places and also for building sand, for it is found to be sandy in places. The bedding, though usually horizontal, is in places sharply inclined toward the south.

The next section begins in the south part of sec. 27, whence a sharp ridge curves across the northwest part of sec. 34 and ends in another fan. This seems to be the end of the chain, though sandy and gravelly knolls west from its northern part in secs. 21 and 27, in a strong moraine near Olivet village, may have been developed in connection with it.

A capping of brown clayey and sandy gravel, 2 to 4 feet thick, covers the uneven and eroded surfaces of beds of assorted material. Beds that contain but little sand are nearly horizontal, but beds with much sand dip quite perceptibly toward the west, some of them 30° or more. Scarcely any of the pebbles exceed 2 inches in diameter, and the great bulk of them are one-half inch or less. Of 221 pebbles having a diameter one-fourth inch or less, 136 were sandstone, limestone, and chert of local derivation; the remaining 85 were Archean, principally granites. Of 52 fine pebbles having a diameter of one-fourth to one-half inch 30 were sandstone and limestone of local derivation and 22 were Archean rocks, principally granites. Coarser pebbles are principally sandstone but no count of them was made. No striated pebbles were observed, but this is perhaps due to abrasion in the glacial stream.

This chain of eskers shows more clearly than is usual in eskers evidence of consecutive northward extensions due to recession of the ice border. The tunnels in which the eskers were formed apparently had a length of only 2 or 3 miles at the most. The apparent exclusion of glacial drainage from the part of the Battle Creek valley in which the esker chain occurs is difficult to explain unless stagnant ice masses persisted along this depression during the time of the glacial drainage through the swamp leading past Olivet station. This drainage is discussed in connection with the Charlotte morainic system.

SMALL ESKERS.

Besides the esker chains above described minor ones are scattered through the moraine in various situations. They consist of single ridges a fraction of a mile in length that are either isolated or are very remotely connected with other eskers. One was noticed in the Grand River Valley about 2 miles north of Onondaga. Several small eskers occur in the valleys of the north tributaries of Portage River in northern Jackson and southern Ingham counties.

OUTWASH.

DISTRIBUTION AND CHARACTER.

The outwash plains on the border of the Kalamazoo morainic system of the Saginaw lobe are among the most conspicuous in Michigan. They are extensive in the reentrant angles between the Lake Michigan and Saginaw lobes and the Saginaw and Huron-Erie lobes, and also along the front of the Saginaw lobe from the meridian of Kalamazoo eastward to the meridian of Marshall, and from Jackson eastward to the Huron-Erie reentrant. Between Jackson and Marshall there are channels formed by the glacial drainage along or near the ice border. The entire system of outwash aprons and channels found discharge southward along the eastern edge of the Lake Michigan lobe to the St. Joseph Valley near Three Rivers, and thence past South Bend to the Kankakee, from which, as now, the drainage led to Illinois and Mississippi rivers and the Gulf of Mexico.

The outwash aprons are throughout indented by numerous basins, some 2 or 3 square miles or more in extent, but the majority only a fraction of a square mile. Many of them are 20 to 30 and some 50 to 60 feet deep. As a whole they occupy nearly as much area as the flat parts of the outwash. On their slopes and beds some bowlders and many sharp hummocks are found. To the eye the basins appear to be morainic, but they are probably due to the presence of masses of stagnant ice during the building up of the outwash plains around them.

On the outwash plains surface bowlders are rare, and the plains rise above the level of the knolls that stand in the basins.

The outwash is very largely fine gravel, though in places on the immediate border of the moraine it carries cobbles and even coarser rock material at the surface. It commonly includes sand and in places is so sandy as to be unsuitable for road ballast. The large amount of the sand is probably attributable to the interruptions to free flow by masses of stagnant ice and also to the wide branching and rather low gradient of the streams flowing away from the ice sheet.

The plain in the reentrant between the Saginaw and Huron-Erie lobes slopes gradually southwestward toward the valley of Wolf Creek, an eastern tributary of Grand River entering at Jackson. It has a width near Grass Lake of about 6 miles. Its altitude at the border of the moraine north and northeast of Grass Lake is about 1,030 feet, but between Grass Lake and Wolf Creek it scarcely exceeds 1,000 feet.

BORDER DRAINAGE.

The border drainage led westward from Jackson at different levels; the altitudes of the outer or southern channels, which pass south of Spring Arbor, are between 990 and 1,000 feet, and those of the northern ones, which lead past Trumbull station west of Jackson, are about 960 feet on the divide between Sandstone Creek, a tributary of Grand River, and Rice Creek, a tributary of Kalamazoo River. The altitude of a channel east of Parma leading more directly to the Kalamazoo Valley is also about 960 feet. The width of these channels is irregular, being commonly one-fourth mile, but ranging up to nearly a mile. They generally have steep banks or low bluffs 15 to 20 feet in height. Their bottoms are marshy, for their gradients are too low for the present small streams to drain them effectually. Portions of the beds in the vicinity of Parma are thickly strewn with bowlders, so that the land is drained could

scarcely be cultivated. It is probable that the northern channels formed the outlet for the outwash tract in the reentrant east of Jackson during much of the time it was receiving outwash from the bordering ice lobes.

The westward descent brings the channels along Rice Creek and Kalamazoo River down to about 900 feet, at which level they open into the gravel plain near Marshall. The altitude of the gravel plain next to the moraine is more than 900 feet for several miles west of Marshall and over a considerable area in the reentrant between the Saginaw and Lake Michigan lobes in northeastern Kalamazoo and southwestern Barry counties, but in the vicinity of Kalamazoo River it is a little less than 900 feet. It seems to have been about 875 feet where the drainage turned southward from the Kalamazoo toward the St. Joseph Valley in eastern Kalamazoo County.

THICKNESS.

The thickness of the outwash deposit is known only in places where wells pass from the surface gravel into underlying till or into bedrock. A few wells northeast of Kalamazoo on an elevated part of the gravel plain enter till at about 40 feet. Directly east of Kalamazoo on the south side of Kalamazoo River the outwash deposit is very thin, so that the till in places is at the surface. This tract, however, has suffered some erosion because of the concentration of so much glacial drainage. In the district between Battle Creek and Marshall the outwash gravel seems to have been but a few feet thick, for the ravines cut down into bowldery drift and in places sandstone is near the surface. The depth of the outwash material in the plain east of Jackson is likely to equal the depth of the basins, which is 30 to 50 feet.

INTERLOCKING MORAINES OF THE SAGINAW AND HURON-ERIE LOBES IN SOUTHEASTERN MICHIGAN.

The “thumb” or southeastern watershed of Michigan, the high divide draining on the east into Lake St. Clair, Detroit River, and Lake Erie and on the west into Lake Michigan and Saginaw Bay, has a rock nucleus but is also occupied by a prominent system of interlocking moraines formed between the Saginaw and Huron-Erie lobes. Moraines of Wisconsin age are to some extent superimposed upon moraines of an earlier (Illinoian) stage of glaciation, for the lobation of the ice in the earlier stage naturally was governed by topography in a manner similar to that in the later stage.

Many years ago, in the Douglass Houghton reports of the first Michigan Survey, the leading topographic features of the divide were so described as to lead one familiar with modern interpretation to infer that it consisted of strong moraines. Years later the system of moraines was recognized and its general features were discussed by Chamberlin,[1] who termed it an interlobate moraine of the Saginaw and Western Erie lobes and who demonstrated its relation to the lobes of the great Labrador ice sheet. It was not, however, until detailed studies were made by the present writer that the presence of moraines and drift ridges of pre-Wisconsin age was noted, or that it was determined that the drift, instead of being a single massive moraine traversing the entire length of the district between the Saginaw and Huron-Erie ice lobes, consists of several interlocking moraines leading up from either side at such angles as to form a reentrant in which the drift is heaped up. This heaping up, repeated in the several moraines which interlock in succession from southwest to northeast, constitutes what is here termed the inter-lob ate morainic belt.

The moraines of the interlocking system in northern Indiana and southern Michigan have already been discussed in connection with the development of earlier moraines of the Saginaw lobe. The present discussion, therefore, begins in southern Jackson County, Mich., where the outer moraine of the Kalamazoo system of the Saginaw lobe connects with the correlative moraine of the Mississinawa system of the Huron-Erie lobe, and extends northeast to southern Lapeer County, north of which no entanglements are found. The entire length of the system in Michigan is 150 miles and its width 25 miles.

DISTRIBUTION AND CHARACTER.

At the place of interlocking flat outwash aprons and lines of glacial drainage strikingly contrast with the sharp knobs of the moraines with which they are connected. When the southwestern end of the interlocking system was forming the reentrant in the ice border appears to have been slight, but with the development of the system it became more marked. As in northeastern Indiana, the Saginaw lobe receded more rapidly than the Huron-Erie lobe, but the reentrant between the lobes receded still more rapidly than the end of the Saginaw lobe, and the Saginaw lobe consequently is more clearly defined in the later than in the earlier moraines of the interlocking system.

The Kalamazoo system of the Saginaw lobe connects with its correlative of the Huron-Erie lobe in southern Jackson County in the vicinity of Hanover, which stands on a small gravel plain in the reentrant between the two ice lobes. North of the village is a moraine of the Saginaw lobe and south and east of it a moraine of the Huron-Erie lobe. The morainic spur developed at the junction is more prominent than either moraine and extends northeastward to a point about 6 miles south of Jackson where it terminates in a kame that stands 200 feet above Grand River, which flows at its northern base. The spur carries numerous knolls 50 to 75 feet high in groups or in short belts between which are lower tracts with small knolls.

At the northeast end of this prominent morainic spur a gently undulating till tract covering an area of about 30 square miles extends from the southern line of Jackson County northward within 3 or 4 miles of the city of Jackson and eastward about to Brooklyn and Napoleon.

It is traversed nearly centrally by a sharp gravelly ridge, 30 or 40 feet high and about 7 miles long, which leads from the south side of Wolf Lake southwestward to the middle of the morainic spur. This ridge is a little broader than a typical esker, being in places nearly one-eighth mile in width, but it appears to have been developed by the same process and to be referable to the esker class. Like the morainic spur it seems to lie very nearly along the line of junction between the Saginaw and the Huron-Erie lobes.

[1]Chamberlin, T. C., Preliminary paper on the terminal moraine of the second glacial epoch: Third Ann. Rept. U. S. Geol. Survey, 1883, p. 328.

From the till plain just described northward past the Michigan Central Railroad and eastward about to the line of Jackson and Washtenaw counties there is a gravel plain, known as the Grass Lake Plain, which rises on the north into a prominent moraine of the Saginaw lobe and on the east into a prominent moraine of the Huron-Erie lobe. It carries numerous basins and connecting sloughs so that only a small part of its surface is up to the level of the plane of deposition. At its northeastern end it extends as a narrow strip scarcely a mile wide for 2 or 3 miles into the midst of the coalesced morainic belt and has its head a mile north of Kavanaugh Lake at the base of Sugarloaf Knob in sec. 32, Lyndon Township, Washtenaw County.

The moraines which border the Grass Lake Plain form a prominent spur about 5 miles wide, from their point of union in northwestern Washtenaw County northeastward about to Pinckney, in southern Livingston County, a distance of perhaps 10 miles. Part of it is within the limits of the Ann Arbor quadrangle. The area of the spur is called by the residents the “short-hill district,” because its thickly set knobs give short but sharp gradients to the roads which traverse it and have very little level surface. It is also thickly set with basins, the largest of which are nearly a mile in longest diameter and one-fourth to one-half mile in width. A number of them contain lakes, some of which are reported to have depths of 75 feet or more, with water surfaces fully 100 feet below the highest neighboring parts of the moraine. The land surface outside the lakes in this morainic spur has a range of about 200 feet in altitude, or from 900 to 1,100 feet above sea level.

From the northeast end of the interlobate spur eastward across southern Livingston County clusters of sharp kames and interspersed gravel plains (see Howell and Ann Arbor topographic sheets) converge toward a gravel plain which leaves Huron River near Portage Lake and leads westward as a prominent line of glacial drainage past Pinckney and around the north end of the interlobate spur to the Portage Swamp, in northeastern Jackson County. The kames rise 100 to 150 feet above the gravel plain and are distributed on both sides of Huron River. Those on the north side appear to pertain to the Saginaw and those on the south side to the Huron-Erie lobe. Back of them on either side of the river are bulky moraines, the one on the north being the probable continuation of the Charlotte system of the Saginaw lobe, and the one on the south belonging to the Huron-Erie lobe, which in northeastern Indiana includes the Mississinawa, Salamonie, Wabash, and Fort Wayne moraines, and in Michigan, from a point near the limits of the Ann Arbor quadrangle northward, the Defiance moraine. The kames were probably formed while the lobes were nearly coalesced over the portion of the Huron Valley east of Pinckney, but the moraines back of them appear to have been formed after the lobes had become sufficiently separated to permit glacial drainage to flow between them.

Near Milford, in southwestern Oakland County, as shown on the Milford topographic sheet, another interlocking of moraines indicates that the two lobes were for a time coalesced down to that point while separated along the portion of the Huron Valley just below. In passing through these interlocking ridges Huron River is obliged to make a series of long curves. The ice border after a time shrank away from these interlocking ridges and receded north and south as well as northeastward. As it receded outwash aprons were formed on its borders, those north of Milford being connected with a strong moraine of the Saginaw lobe and those east and south of Milford with the Huron-Erie lobe. A prominent sandy plain east of Milford, known as Commerce Plain because it covers much of Commerce Township, and its continuation down Huron River are both much lower than the outwash plains north of Milford, for the latter are held up by the series of interlocking ridges near that village, through which only narrow gaps lead into the Huron Valley.

Gravel plains, which are extensive from Commerce Township northeastward to Oxford, are crossed or interrupted by two morainic ridges. One ridge, shown on the Pontiac topographic sheet, leads northwestward from Orchard Lake to White Lake and separates Commerce Plain from Drayton Plain. Another ridge runs east from Clarkson village and separates Drayton Plain from Oxford Plain. These ridges connect at either end with prominent morainic belts trending with the gravel plain, the moraine at the north being the Saginaw and that at the south the Huron-Erie. East of Drayton Plain, in the district immediately north and west of Pontiac, a till plain covers about 15 square miles. This is the only conspicuous till plain along the junction of the two lobes, except that in Jackson County, already noted.

From the slopes of the different portions of the gravel plain some inferences have been drawn as to the ice lobes that contributed the principal outwash. The Commerce Plain seems to have been formed by the Huron-Erie lobe, for, as shown on the Pontiac topographic sheet, it has a northwestward slope from the Huron-Erie moraine to Huron River, which follows its northwest edge. Drayton Plain, on the other hand, seems to have been built up largely by out-wash from the Saginaw lobe, for it has a southeastward slope from the moraine of that lobe to Clinton River, which follows its southeast border. Oxford Plain seems to have been

filled by outwash from the east and the west and the head of the reentrant on the north.

As the ice shrunk back from the north end of Oxford Plain into southern Lapeer County outwash from along its edge filled the low places among the morainic knolls to altitudes nearly 100 feet above Oxford Plain, without, however, covering the principal knolls.

Several prominent kames lie along the line of the moraines on each side of the gravel plain from Milford up to Oxford Township. The most prominent are fully 200 feet in height. Most of them rise above the 1,100-foot and several above the 1,200-foot contour, and one about 6 miles northeast of Oxford appears by aneroid to reach an altitude of 1,300 feet. Oxford Plain is about 1,060 to 1,075 feet at its northern edge, Drayton Plain about 1,000 feet at its northern edge, and Commerce Plain about 940 feet at its eastern edge. The most prominent knoll between Commerce and Drayton plains rises to 1,111 feet. The Pontiac and Rochester topographic sheets indicate that a knoll about 2 miles west of Clarkston reaches 1,201 feet; Pine Knob, 21/2 miles east of Clarkston, 1,221 feet; Mount Judah, 6 miles north of Pontiac, about 1,180 feet; and Bald Mountain, 8 miles northeast of Pontiac, 1,195 feet.

TOPOGRAPHY.

The present relief of the divide above the lowlands on either side is only in small part due to drift, for the rock surface of the divide stands fully as high above the rock surface of the lowlands as the present drift surface stands above the lowland drift surface. The drift deposits are generally as thick in the lowlands as on the divide; indeed, in small areas along or near the divide in southwestern Jackson and neighboring parts of Calhoun, Hillsdale, and Branch counties, the drift deposits are insufficient to conceal the rock hills, despite the fact that the hills have but slight relief above the thick drift filling that covers the lower land. In some of these hills the rock attains an altitude of over 1,100 feet above sea level, higher than in any other part of the southern peninsula, but along much of the divide it is only 800 to 900 feet on the hills and ridges and much lower in the drift-filled interspaces. The altitude of the drift surface is highest in two somewhat widely separated localities, one in Hillsdale County where the rock is exceptionally high, and the other in northern Oakland County where the drift aggregation is very great. In both places the maximum altitude is about 1,300 feet and in numerous knolls it is 1,200 feet or more. The drift surface along this divide ordinarily is not far from 1,000 feet above sea level, or about 400 feet above the surface of the neighboring Great Lakes.

STRUCTURE OF THE DRIFT.

THICKNESS.

The thickness of drift is considerably less on the Saginaw than on the Huron-Erie part of this interlobate system, for the Saginaw part lies on the table-land of sandstone belonging to the Marshall formation, and the Huron-Erie part covers the lowland underlain by the Coldwater shale. The general altitude of the rock surface is 150 to 200 feet greater where the sandstone is the upper rock formation than where the Coldwater shale immediately underlies the drift. As the general altitude of the drift surface on the Saginaw side of the interlobate is not much higher (possibly 50 feet) than on the Huron-Erie side, the depth to rock is 100 to 150 feet greater on the Huron-Erie side. Along the ridges of the Huron-Erie lobe it is generally about 250 to 300 feet, whereas on the ridges of the Saginaw side it in few places reaches 200 feet. At the north end of the interlobate system in northern Oakland and southern Lapeer counties the highest ridges may carry 400 feet of drift, for the rock surface at Orion is about 825 feet above sea level and several of the prominent ridges and knolls rise above 1,200 feet.

The sandstone of the Marshall formation underlies a prominent moraine of the Huron-Erie lobe in western Washtenaw County, and its eastern border seems to be within the limits of the Huron-Erie lobe from Washtenaw County southwestward across northwestern Lenawee County and central Hillsdale County. In that portion of the morainic system the thickness of drift is about the same on the Huron-Erie as on the Saginaw side and scarcely reaches 200 feet on the most prominent points. Rock outcrops at a few points in Jackson and Hillsdale counties, but among them the drift generally is 100 feet or more thick.

The amount of drift referable to the Wisconsin invasion is to a large degree undetermined. In places in Washtenaw County in the vicinity of Ann Arbor the change from soft till to hard till, thought to mark the line between Wisconsin and pre-Wisconsin drift, is found at a moderate depth, but more commonly at 100 feet or more. In Hillsdale County evidence of the presence of drift sheets of two distinct invasions is still clearer, beds of black muck or swampy deposits being found at the base of the soft till. A few miles south of Hillsdale this black muck is found in wells over an area of several square miles. It lies about 100 feet below the surface, thus corresponding to the general depth to the hard till on the moraines in the vicinity of Ann Arbor. The surface of the hard till in the vicinity of Ann Arbor appears to be very uneven, the depth to it ranging from a few feet to about 130, either because the topography of the older drift was morainic or because it was carved by interglacial erosion. It is much higher in the prominent morainic ridge leading southwest from Ann Arbor and in a prominent tract east of the city than it is on the lowlands between. In places east of Ann Arbor it comes nearly to the surface on the morainic knolls. From the few data available it appears probable that the pre-Wisconsin drift in this vicinity contained prominent ridges which have not been completely concealed by the Wisconsin drift.

It is thought that the prominent kames along the borders of Huron River near the axis of this morainic system were developed during the Wisconsin ice invasion and that the drift at this latest invasion was built up from a level as low as the bottoms of the basins of the lakes and swamps which abound in this region. Some of these lakes have depths that exceed 100 feet. This fact and the fact that the wells on the borders of the lakes penetrate great depths of assorted material are thought to indicate that the deposition of morainic and outwash material at the last ice invasion has produced all that is found from the level of the bottoms of the lakes to the tops of the bordering knolls. At least no suggestion of a change in the constitution of the drift has been noted.

COMPOSITION.

The drift of the interlobate system in the area in which the ice lobes coalesced changes its texture as it passes back into the districts lying beneath each of the ice lobes. Along the line of coalescence the drift is gravelly and sandy with only scattered deposits of clayey till, the kames are made up largely of gravel and cobble, and the outwash aprons are composed of gravel and sand. In passing back into the moraines on either side, however, the deposits change first to a loose-textured drift with large numbers of cobblestones in a sandy matrix, and a little farther back to a clayey till similar to that in the moraines outside the interlobate tracts. Commonly several miles is required for the transition, but in places, as, for instance, near Pontiac, a clayey till is found on the immediate borders of the gravel plain. The prominent moraine which leads from Pontiac southwestward past Ann Arbor is characterized by clayey till along much of its course in Oakland and Washtenaw counties. At the northeast it is near the edge of the gravel plain, but toward the southwest it bears away, passing east of an older moraine. On the Saginaw side of the interlobate tract the drift is generally loose-textured nearly to the inner edge of the morainic belt, though it is interrupted in a few places by a stiff clayey till, as, for instance, in the northern part of the interlobate spur west of Portage Lake in southern Livingston County. In places a thin veneering of a somewhat clayey till thickly set with bowlders overlies gravelly drift of great depth. This is the case on the drift of the Huron-Erie lobe in northern Washtenaw and southern Livingston counties from Whitmore Lake westward to Portage Lake, and in eastern Livingston and northwestern Oakland counties on moraines of the Saginaw lobe.

BOWLDERS.

Bowlders are exceptionally numerous all over the Saginaw portion of the interlobate moraine, there being scarcely a square mile outside the gravel plains in which they are not conspicuous. On the Huron-Erie side of the interlobate system they tend to segregation in belts, though they are generally numerous for several miles back from the edge of the gravel plain. Bowlder belts run usually about parallel to the main ridges, but are not confined to the ridges. Thus one in western Washtenaw County, which has been represented on the map in the Ann Arbor folio, leads southwestward from Dexter midway between two prominent moraines. These belts were probably deposited along the edge of the ice in the course of its recession and may mark brief halts which were insufficient to produce a moraine. The Fort Wayne moraine, which crosses Huron River near Ann Arbor, has remarkably few bowlders on its surface in Washtenaw County compared with the number in outside districts.

Few of the bowlders are more than 5 or 6 feet in diameter and are largely granite. The red jasper conglomerate bowlders are perhaps more conspicuous in this interlobate morainic system than elsewhere in the southern peninsula. Many have been gathered up for dooryard ornaments, and they are frequently worked into the foundations of dwellings because of the attractiveness of the bright-red pebbles. Conglomerates of other kinds are also present in notable amount and quartzites are not rare. On the Huron-Erie portion of the morainic system in Washtenaw and Lenawee counties limestone blocks from the formations at the head of Lake Erie are frequently found; some of them are large.

The rock constituents of the drift are very largely derived from formations within a few miles of the morainic system. The moraines of the Huron-Erie lobe contain limestone from the Silurian and Devonian formations, which outcrop in the southeastern corner of the southern peninsula and in neighboring parts of Canada; the black Devonian shale is also conspicuous. The large amount of clay present in the eastern edge of the moraines of the Huron-Erie lobe may be referable to the accessibility of shale material from the underlying Coldwater shale, as well as to the imperfect drainage conditions.

On the Saginaw portion of the morainic system sandstones, derived in part from the coal measures and in part from the Marshall formation, form a conspicuous part of the coarser rock constituents. Coal is frequently reported from all through the Saginaw part of the morainic system, even from places some miles outside the limits of the coal measure formations. It need scarcely be suggested that the presence of coal in paying quantities should not be inferred from the finding of masses of coal in the drift.

GLACIAL DRAINAGE.

The glacial drainage of the interlobate district is a matter of some interest as it departs considerably from the present lines. It was governed by the bordering ice lobes and only to a slight extent by the slopes of the land surface.

When the ice border stood at Hanover in southern Jackson County the water from the reentrant angle followed South Fork of Kalamazoo River to the bend near Homer in southeastern Calhoun County, where it cut across the narrow space that now separates the St. Joseph and Kalamazoo valleys and entered the St. Joseph Valley. It followed this valley to the great bend at

South Bend, Ind., where it passed into the headwater part of Kankakee River and thence to Illinois and Mississippi rivers and the Gulf of Mexico.

When the ice border stood on the north and east sides of Grass Lake Plain in eastern Jackson and western Washtenaw counties the drainage was not northward from Jackson down Grand River but was westward through a series of swampy channels that led across to the Kalamazoo through western Jackson County. It seems to have followed the present course of the Kalamazoo about to the site of the city of Kalamazoo and thence went southward to the St. Joseph Valley near Three Rivers and on to the Kankakee past the site of South Bend.

When the ice border stood near Milford the drainage followed down Huron River about to Portage Lake. From there it continued westward to the Portage Swamp in northwestern Jackson County and thence to the Grand River valley just north of Jackson. After following Grand River to Eaton Rapids it passed westward, as shown on the Lansing topographic sheet, through a swamp now utilized by the Michigan Central Railroad to Charlotte, where it entered Battle Creek. Thence it passed to the Kalamazoo and apparently followed the course of the present river to the site of Plainwell, a few miles below Kalamazoo. From there it seems to have passed southwestward for a time through the low district west of the Kalamazoo morainic system to the head of the Kankakee at South Bend, a part of its course being through long pools or lakes.

With the northward recession of the Saginaw ice lobe the drainage continued down Grand River a few miles beyond Eaton Rapids and then, as shown on the Lansing topographic sheet, passed westward to the Thornapple, which it followed to the bend below Hastings. Thence it passed southward by Gun Lake and down the Gun River valley to the Kalamazoo. It seems to have passed directly across the Kalamazoo Valley and to have reached the headwaters of Paw Paw River in northeastern Van Buren County. Thence it seems to have followed down the Paw Paw Valley to a glacial lake, the incipient Lake Chicago, that filled the lower course of the Paw Paw and St. Joseph valleys at the time when the Lake Michigan lobe extended but little beyond the limits of the present lake. From this small glacial lake the drainage led along the border of the ice to the south end of the Lake Michigan basin (see pp. 226-227) and thence into Desplaines, Illinois, and Mississippi rivers. It is not entirely certain that the drainage from the headwater part of the Huron took this course through the Thornapple Valley; it may have followed the course past Ann Arbor next to be considered.

When the Huron-Erie ice lobe had receded southeastward to the site of Ann Arbor the glacial drainage followed down the Huron Valley, with perhaps a slight deflection south of the valley near Dexter. On reaching the edge of the ice sheet near Ann Arbor it turned southwestward through a large swampy valley (see Ann Arbor folio and topographic sheet) that passes just north of Pittsfield Junction and Saline to the Raisin Valley, in southwestern Washtenaw County. Thence it followed down the Raisin Valley to the vicinity of Adrian, where it entered Lake Maumee, whose outlet led past Fort Wayne, Ind., to the Wabash.

TILL PLAINS.

Among the morainic ridges of the Huron-Erie lobe in Oakland, Washtenaw, Lenawee, and Hillsdale counties narrow strips of till plain have surfaces much smoother than those of the neighboring ridges. The till plains are not continuous, however, for many miles, being broken by the interlocking ridges. Near the State line of Michigan and Ohio the ridges become more widely separated and the till plains continue distinct for many miles in northeastern Indiana and northwestern Ohio.

One till plain occupying an area of 50 or 60 square miles lies in the southern part of Jackson County east of the Hanover interlobate spur. Its surface is gently undulating, with swells 10 to 20 feet high, but is decidedly smoother than that of the bordering moraine west of it. Bowlders are about as numerous as on the moraine. It is a region of rather thin drift, rock being struck in many places at 30 feet or less. The till is of loose texture and seems to have considerable sand and gravel associated with it.

A narrow till plain 8 to 10 miles long and only 2 or 3 miles wide lies in northern Hillsdale County a few miles northeast of the city of Hillsdale. It is very elevated, the greater part of its surface being between 1,100 and 1,200 feet above sea level. The surface is gently undulating but lacks the sharp knolls and basins found in the neighboring moraines on either side. The drift here is 60 to 100 feet or more in depth and contains considerable clayey till, so that many wells are driven nearly to the rock before obtaining water.

In the southern part of Hillsdale County a till plain on the outer border of the Wabash moraine has a width of about 3 miles and a length of 7 or 8 miles. Its surface is very gently undulating and in places flat. The till is compact and clayey and extends to a considerable depth; wells in it have not reached rock at a depth of 100 feet.

Another till plain in Hillsdale County lies between the Wabash and Fort Wayne moraines. Its southern portion is on the west side of St. Joseph River and its northern portion is west of the headwater portion of Bean Creek. It lies mainly in southeastern Hillsdale County but extends northeastward as a narrow strip a short distance into Lenawee County. It continues between these two moraines down the St. Joseph Valley into Indiana. The till is very clayey and extends to considerable depth.

An extensive till plain lies in the western half of Lenawee County on the east side of the Fort Wayne moraine. Its width is 6 to 8 miles and it runs from the northern edge of the county in a course west of south to the southwest

corner. It continues into Ohio and widens southward as indicated in the discussion of the Fort Wayne moraine. At the northern end, in southwestern Washtenaw County, it is cut off by interlocking ridges. This till tract has an undulating surface, in places nearly as uneven as the bordering part of the Fort Wayne moraine. It is composed very generally of a stiff clayey till.

In western Washtenaw County there is a tract covering nearly 100 square miles in which the surface is less definitely ridged than on the bordering morainic tracts to the east and west. It has, however, several large gravel knolls or kames (see Ann Arbor folio and topographic sheet) rising 75 to 100 feet or more above the general level, as well as numerous small knolls, and an esker known as the Lima esker. Marshy basins lie on the interfluvial tracts, and narrow strips of marsh border nearly all the streams. The surface is therefore far from flat and can be called a plain only when contrasted with the neighboring ridges, whose surfaces are a succession of steep hills and ridges. Owing to the loose texture of the drift the roads in dry seasons work into loose sand. The drift contains many small stones 3 to 6 inches in diameter that are apparently scattered through it rather than arranged in definite beds. Bowlders are not rare on any part of the surface and are especially numerous in narrow strips which may properly be termed bowlder belts. One of these (see Ann Arbor folio) leads entirely across the plain from the vicinity of Dexter southwestward to the vicinity of Pleasant Lake, passing near the east end of the Lima esker and running past some prominent kames south of Lima Center.

In northern Washtenaw County strips of till alternate with gravel plains that lead northwestward toward the Huron Valley. The till is as a rule thickly strewn with bowlders, but its surface is comparatively smooth. It ranges from a clayey to a very loose textured deposit.

ESKERS.

CHARACTER AND DISTRIBUTION.

A few elongated gravel ridges of esker type terminate in this interlobate system and numerous short ridges of similar form and constitution which should probably be classed with eskers. The short ones may be passed with the mere statement that they occur at various points in the Saginaw part of the interlobate tract from eastern Livingston County northeastward across northeastern Oakland County. Most of them are only 10 to 20 feet in height, 100 yards or less in width, and a mile or less in length. They commonly lie in swampy tracts, though some of them are on the slopes of the prominent parts of the moraine. They are composed of well-assorted gravel and are often drawn on for road material.

LIMA ESKER.

The Lima esker is the only prominent representative of this class of glacial ridges noted on the Huron-Erie side of the interlobate tract. It is situated 10 to 15 miles west of Ann Arbor in Lima Township, Washtenaw County, along a branch of Mill Creek that forms the outlet of Fourmile Lake. (See Ann Arbor folio.) Its length is about 6 miles, its eastern end being in sec. 24 and its northwestern end in sec. 4, Lima Township. It runs west for about 3 miles and then near Lima Center makes an abrupt turn to the north; aside from this deflection it follows a somewhat winding course, and in one place about 11/2 miles north of Lima it describes a letter S. It rests on the uneven surface of the slopes of the valley or depression through which the outlet of Fourmile Lake flows, rising and falling 30 feet or more with the surface on which it lies. Its relief in few places is more than 20 feet, and it is interrupted by several small gaps.

Gravel pits opened in the esker indicate that it was formed by a stream flowing west and north, or in a direction opposite to that of the present drainage. At its northwest end is a sharp gravel knoll about 50 feet high which it is thought may have been built by the same drainage that formed the esker. It seems probable that the esker was deposited at a sufficient height above the base of the ice to correspond with the height of this knoll, though it is possible that water might gush up at the edge of the ice, as was noted by Russell in the Malaspina Glacier, and deposit material there at a level higher than that of the tunnel through which it was flowing.

The material of the esker is not markedly waterworn, and the preservation of fragile pieces of Devonian shale of considerable size in it is thought to indicate that some of the material may have been subjected to but slight transportation after it was released from the ice. The esker development seems to have been the closing event of the subglacial drainage, its material being deposited along the line of the drainage because the stream had insufficient strength to carry it to the ice border.

ACKERSON ESKER.

The gravel ridge to which the name Ackerson esker is applied was noted in the discussion of the interlobate spur in southern Jackson County. (See p. 197.) It seems to stand very near the junction of the Saginaw and Huron-Erie lobes and terminates in the morainic spur formed between them. It passes from the west end of Wolf Lake past Ackerson Lake through a gently undulating till plain and strikes the interlobate spur about 8 miles south of Jackson. Its structure from top to bottom is revealed in a cut on the Cincinnati Northern Railroad near Ackerson Lake. It contains very coarse material—much coarser than is ordinarily found in eskers—reaching a maximum in small bowlders nearly a foot through and slabs 2 feet or more long. The coarse material is quite generally present, especially southwest of Ackerson Lake. The ridge is also more massive than the ordinary esker, being in places about one-eighth mile in width, but it has the abrupt embankment-like appearance and the customary great length of ridges of this class, being nearly continuous for about 7 miles and standing 30 to 40 feet above the border tracts along much of its course. Possibly it is the product of a

combination of ice deposition with subglacial drainage, and this may account for the coarseness of its material and for its unusual size.

CHARLOTTE MORAINIC SYSTEM OF THE SAGINAW LOBE.

COURSE AND DISTRIBUTION.

The Charlotte morainic system, which takes its name from the county seat of Eaton County differs from most morainic systems in having a rather vague outer border, the nearly plane till tract on the south rising gradually, in the space of 1 to 2 miles or more, into a pronounced moraine. A few morainic spurs and some eskers extend southward on to the plain. The topography seems to be such as might result from a mere halt in the recession of the ice border. The large number of eskers leading into it from the inner border plain, and especially those in the midst of the moraine, seems to indicate that the ice was nearly stagnant, and the character of the outwash and the ice-border drainage seem consistent with such an interpretation.

This morainic system connects at the west with the Valparaiso morainic system of the Lake Michigan lobe and is believed to be the full equivalent of that system, though it is less bulky. The outermost ridge of the Charlotte system connects with a ridge of the Valparaiso system at Dias Hill, about 12 miles south of Grand Rapids; a second and stronger ridge connects at the bend of Grand River just north of Grand Rapids; and a third connects near Cedar Springs, about 15 miles north of the same city. This recession of about 24 miles in the reentrant angle between the Saginaw and Lake Michigan lobes is greater than that at any other place along the line of the Charlotte morainic system, the ridges elsewhere being commonly combined into a single belt 4 to 8 miles wide.

The outer ridge leads from Dias Hill, in southern Kent County (see Grand Rapids topographic sheet), southeastward across the northeast corner of Allegan County to Thornapple River at Middleville, in Barry County. The outer edge of the second ridge follows the west side of Thornapple River north from Middleville nearly to Grand River before it crosses the stream. East of the Thornapple the two ridges combine into a single belt which lies along the north side of Thornapple River from Middleville to Hastings. At Hastings the outer ridge crosses to the south side of the river and follows its south bluff past Nashville and Vermontville for 18 miles. A few miles east of Vermontville the second ridge crosses the river, which has been deflected to the south, and the two ridges again combine in a single belt that leads past Charlotte. A short distance east of Charlotte the belt breaks up, as shown on the Lansing topographic sheet, into two and in places three ridges, separated by narrow swampy depressions. Beyond Grand River, however, just below Eaton Rapids, a single broad belt leads eastward across the Mason, Fowlerville, and Howell quadrangles in southern Ingham and southwestern Livingston counties to connect with the correlative morainic system of the Huron-Erie lobe in the Howell and Milford quadrangles in the southeastern part of Livingston and southwestern part of Oakland counties. The combined system of moraines and their included outwash aprons form the conspicuous interlobate belt that leads northeastward across Oakland County into southern Lapeer County. The Charlotte system becomes blended with the inner part of the Kalamazoo morainic system in southeastern Ingham County and has no distinct development farther to the east.

A third prominent moraine that seems referable to this system separates from the other moraines a few miles north of Hastings and leads northward through the southwestern part of Ionia County to Grand River valley just above the mouth of Flat River. It turns westward across Flat River into Kent County and merges with the second moraine of the system. The combined belt connects with a correlative morainic belt of the Lake Michigan lobe near Cedar Springs in northern Kent County. A morainic spur extending from it north-northeast to Greenville may perhaps be considered a part of this third belt. So also may somewhat isolated morainic strips farther north in western Montcalm County. It was probably in connection with the development of the Charlotte morainic system of the Saginaw lobe and the Valparaiso system of the Lake Michigan lobe that the strong interlobate moraine, which was discussed in connection with the Kalamazoo morainic system and which covers much of Mecosta and Osceola counties, was given its surface expression.

TOPOGRAPHY.

Along much of the morainic system, and especially in the portion distinct from the Lake Michigan and Huron-Erie lobes, the topography is of a swell and sag type, with many separate knolls 10 to 20 feet in height and some in groups or chains 50 to 75 feet in height. The relief above the outer border plain is slight, for a basement ridge is generally lacking and the moraine is merely an assemblage of knolls and sags. In the reentrant angles between the Saginaw and Lake Michigan lobes and between the Saginaw and Huron-Erie lobes there are a few very prominent knolls ranging from 100 to 200 feet in height. Dias Hill rises to 1,032 feet, or nearly 200 feet above the surrounding country, in an irregular mass covering scarcely 2 square miles. A range of hills east of Rockford, in north-central Kent County, known as the Prospect Hill Range, is about 100 feet in height, 3 miles in length, and less than one-half mile in width. Another range about 8 miles farther north, lying east of Cedar Springs, is of similar dimensions to the Prospect Hill Range. These are the principal prominent elevations in the vicinity of the Michigan and Saginaw reentrant.

Eastward from the reentrant the first prominent group of knolls is on the east side of Thornapple River. It begins opposite Middleville and extends northward about 7 miles. Its height is about 100 feet above the highest

terrace of the Thornapple and in several points exceeds 900 feet above sea level. It trends at a right angle to the moraine and stands in the direct line of continuation of the prominent interlobate spur between the Lake Michigan and the Saginaw parts of the Kalamazoo morainic systems. This relation has suggested the possibility of its being an overridden part of the interlobate spur, though full evidence to that effect has not been found. From 3 to 6 miles east of this range other prominent hills are arranged in small groups whose highest points considerably exceed 900 feet. The surrounding morainic tracts rise to about 850 feet.

Immediately north of Hastings the moraine is traversed by a chain of lakes which leads across it nearly at right angles. Most depressions of this sort have been utilized by rivers as passages, but this one is not so occupied.

The Thornapple Valley, which lies between the two members of the morainic system in eastern Barry and western Eaton counties, is fully 100 feet below the bordering moraines and nearly a mile in average width, yet it seems to have suffered only a small amount of erosion either by the present river or by its fluvioglacial predecessor. It is merely a large depression left by the ice.

The portion of the morainic system south of Thornapple River is deeply indented by long depressions which extend from north to south nearly through it and whose bottoms are but little above Thornapple River. Some short gravelly ridges of esker type lie in these depressions. A similar deep depression traverses the moraine on the north side of the river immediately west of Vermontville, and this also carries esker-like gravel ridges.

From Vermontville eastward across Eaton County to the Grand River valley near Eaton Rapids (see Lansing topographic sheet) the inequalities of surface are due more largely to deep depressions in the morainic system than to prominent knolls, though there is a knoll just north of Charlotte about 75 feet in height and several along the Grand River valley below Eaton Rapids 40 to 50 feet in height. Some of these depressions parallel the trend of the moraine, thus separating it into a system of parallel belts, but some lead directly across one or more of the morainic members. These depressions are largely occupied by swamps. Some have evidently been utilized by lines of glacial drainage, but others still preserve the irregularities of contour left by the ice sheet. In one there is an esker whose southern terminus is at the city of Charlotte. (See p. 209.)

East of Grand River in southern Ingham County (see Mason topographic sheet) the moraines are combined into a single belt, whose borders are very irregular both on the north and the south. The north border is deeply indented by swampy tracts, some of which extend nearly through the morainic belt. Some of these are occupied by eskers which head on the till plain north of the moraine. The south border shows some recesses, one of which contains the head of the Rives esker system (p. 192) and some spurs extending to the south. Some of these spurs include esker-like gravel ridges, and some small eskers stand between the spurs in the plains just outside the moraine. The range between the tops of the highest knolls and the beds of the deepest depressions is 75 to 100 feet7 but few of the knolls are over 50 feet high and most of them are 25 feet or less. Among the knolls are numerous swampy basins, but lakes are not common.

In Livingston County, where the Charlotte system is more or less closely combined with the Kalamazoo, the northern portion of the combined system resembles the Charlotte system in Ingham County. Swampy depressions containing eskers (see Fowlerville and Howell topographic sheets) extend from the till plain southward into the edge of the morainic system and in some places connect with outwash aprons which head well back into the moraine from the south border. The breaks in the moraine thus seem to be due to a combination of subglacial and extraglacial drainage.

The large kames in the midst of the interlobate tract lie, some in the Saginaw and some in the Huron-Erie portion. Some prominent ones, indicated on the Howell sheet, are found near the inner border, as, for instance, a kame 3 miles west of Howell, on which the tuberculosis sanitarium stands, and others 3 or 4 miles northeast of Howell. Three kames west and south of Chilson reach the 1,100-foot contour, rising about 150 feet above the bordering country. In the northeastern portion of Livingston County, in Tyrone and Hartland townships, the inner part of the moraine is very prominent; points in central Tyrone Township rise above 1,200 feet and considerable areas in both townships rise above 1,100 feet, though the neighboring plains on the inner border rise to less than 1,000 feet. This prominent part as well as the lower part in the western portion of the county is traversed by deep swampy depressions, some of which pass entirely through to the lines of glacial drainage leading into the interlobate gravel plains. On the inner border of the morainic system, northeast and east from Howell, till plains with an area of 2 to 6 square miles are nearly surrounded by tracts with a hummocky topography, like the neighboring moraine. The conditions are so complex both in the moraine and on its inner border that it is difficult to set forth the details, but reference to the topographic sheets will serve to make many features clear. The leading features of the interlobate system in Oakland and southern Lapeer counties have already been discussed. (See pp. 196-199.)

STRUCTURE OF THE DRIFT.

Along the entire length of the morainic system the drift is exceedingly variable. In the more subdued portions the knolls are commonly capped with till, but in many places excavations show them to have a nucleus or pocket of gravel and sand; little of the surface material shows a stiff clayey constitution, though a large part of it would be classed as till rather than as assorted material. The

prominent portions of the moraine are made up very largely of assorted material and are to be classed as kames and eskers. This morainic system includes, perhaps, more small eskers than any other in Michigan, and it receives the southern termini of some of the most conspicuous eskers of the State. Some of the esker ridges have a nucleus of gravel and sand with a thin capping of till, a feature which suggests that they were formed near the base of the ice sheet at a horizon low enough to permit the deposition of the englacial material on them.

The amount of assorted material along the line of this morainic belt is such that wells may easily be obtained at moderate depths nearly everywhere. In Ingham and Eaton counties, however, where the drift is of moderate depth, it is customary to continue the wells into the underlying sandstone, for the water there obtained is softer than that from the drift formations.

The thickness of the drift is from 40 to 75 feet along much of the moraine in Eaton and Ingham counties, but is much greater in Livingston and Oakland counties. In Kent County the distance to rock is moderate in the vicinity of Grand Rapids and also near Lowell, but elsewhere the rock surface lies so low that wells have not reached it.

OUTER BORDER DRAINAGE.

At the time the Charlotte morainic system was forming the drainage appears to have been westward from the interlobate tract in Oakland County through a chain of swamps and partly gravel filled valleys along or near the outer border of the system as far as Charlotte and thence down Battle Creek to the Kalamazoo. The drainage left Huron River near the bend at the line of Livingston and Washtenaw counties and passed westward by Pinckney and Anderson and Unadilla to northeastern Jackson County into the Portage Swamp, which emptied into Grand River a short distance north of Jackson. It followed the general course of Grand River valley to a point immediately east of Eaton Rapids, though it was perhaps deflected northward for a short distance through a sandy tract known as the Montgomery Plains, for the present river immediately south of this sandy tract flows in a very narrow valley which does not appear to have carried the glacial drainage and which was probably occupied by stagnant ice. Beyond Eaton Rapids the ice still blocked the channel, and the glacial waters (see Lansing topographic sheet) flowed westward through the swamp traversed by the Michigan Central Railroad between Eaton Rapids and Charlotte. Numerous tributary lines of glacial drainage led southward from the edge of the Charlotte morainic system in Livingston and Ingham counties to join this main line of drainage.

The glacial drainage seems to have had a good gradient only in Oakland County, for in southern Livingston, northwestern Washtenaw, northeastern Jackson, southwestern Ingham, and southern Eaton counties there is scarcely any descent. The altitude of the gravel plain in southern Livingston County is between 900 and 920 feet, much of it being less than 910 feet. That of the Portage Swamp in northeastern Jackson County appears also to be fully 900 feet. That of the Montgomery Plains east of Eaton Rapids, where the glacial drainage seems to have made a detour to the north of the Grand River valley, is above 900 feet and that of the swamp between Eaton Rapids and Charlotte is 900 to 903 feet in its western portion, as shown by the Lansing topographic sheet. In passing down Battle Creek very little descent seems to have been made in the first 10 miles, there being a channel marking an old detour of the glacial drainage to the west of the present stream past Olivet station, whose floor is 885 to 890 feet. Rapid descent begins south of Olivet station, the channel floor being 870 feet at Bellevue and about 825 feet at the city of Battle Creek, 12 miles below Bellevue. The distance having a very low gradient is about 75 miles, and the amount of fall is scarcely 20 feet. It is probable, therefore, that the waters were ponded, but were in sufficient volume to give a strong current through to the lower portion of Battle Creek. With the exception of the Portage marsh in northeastern Jackson County, where the water may have spread out to a width of 3 or 4 miles, the topography is such as to indicate that the width generally throughout this 75 miles of ponded drainage was scarcely more than a mile, and in places it must have been reduced to less than one-half mile. The course of the glacial drainage just outlined could not have been different under the conditions of altitude that obtained in the region while the ice was filling the portion of the Grand River valley below Eaton Rapids. To have passed through any of the channels utilized during the development of the Kalamazoo morainic system the waters would have been compelled to rise to about 960 feet.

From the city of Battle Creek the glacial drainage followed down the Kalamazoo Valley to the vicinity of Plainwell, descending from 825 feet to 750 feet in about 35 miles. Thence the drainage took a southwestward course through the low plain west of the Kalamazoo morainic system, descending to about 725 feet in the vicinity of Dowagiac. There a narrow lake (Lake Dowagiac) seems to have extended from Dowagiac to South Bend, Ind., from which the discharge was southwestward along the Kankakee to Illinois and Mississippi rivers and the Gulf of Mexico.

From the portion of the border of the Charlotte morainic system west from the meridian of Charlotte the drainage was inconspicuous to the vicinity of Hastings, but from that city up to the reentrant angle near Dias Hill in southern Kent County it was large, producing a broad outwash apron whose altitude in the reentrant angle between the Saginaw and Lake Michigan lobes is about 800 feet. The waters passed southward along the eastern front of the Lake Michigan lobe to Plainwell and there joined the longer line of glacial drainage just described.

With the northward extension of the reentrant angle between the Saginaw and Lake Michigan lobes, past the city of Grand Rapids, and a slight westward shrinkage of the border of the Lake Michigan lobe a line of glacial drainage with bed below the 700-foot contour, well shown on the Grand Rapids topographic sheet, was opened southward from Grand Rapids past Carlisle and Ross to Rabbit River.

With the recession of the reentrant into southwestern Montcalm and southeastern Newaygo counties the glacial drainage took a southward course between the ice lobes for a short distance and then turned into districts which had just been abandoned by the Lake Michigan lobe. (See pp. 220-221.)

INNER BORDER.

GENERAL CHARACTER.

The interval between the Charlotte morainic system and the next later moraine of the Saginaw lobe is filled principally by a till plain, whose surface is in large part very smooth and much of which is included in the Lansing, Mason, Fowlerville, and Howell quadrangles. In Ingham and Livingston counties, however, it is traversed by several eskers, which lie for the most part in shallow swampy depressions or esker troughs and which lead somewhat directly toward and terminate in the morainic system. Some of these swampy depressions are not occupied by eskers or are occupied by them for a part of their course only.

On this inner border tract there are a few very prominent knolls and some undulating strips nearly surrounded by till plains. Some of these knolls northeast of Howell are elongated in the direction of ice movement and form short chains, as is the habit with eskers, but are irregular in shape, in some places reaching a width of nearly one-fourth mile. They are clearly shown on the Howell topographic .sheet in secs. 16, 17, 20, 21, 28, and 29, Oceola Township. Though composed largely of gravel and sand they are partly veneered with bowldery till. Their height is from 60 to 100 feet. The longest chain, which extends from the north part of sec. 16 southwestward into the edge of sec. 20, has a length of about 11/2 miles. The chain in secs. 21 and 28 is less than a mile in length and so also is the chain in sec. 29.

A rather conspicuous undulating strip about a mile wide with swells 10 to 30 feet high runs east and west through northern Barry and Eaton counties a few miles south of Grand River, Roxana being on it. In places it is nearly in contact with the Charlotte morainic system and in places is separated from it by a till plain 2 to 5 miles wide, and it appears to merge at both ends in that morainic system. Farther east in northwestern Ingham County an undulating strip leads from the Charlotte morainic system at the bluff of Grand River northeastward past Holt to the Cedar Valley east of Okemos. The knolls in it are, however, low and scattered and parts of the strip are difficult to differentiate from the bordering till plains. These strips have in places some resemblance to the slender and in places ill-defined members of the next morainic system, and may perhaps belong with that system.

The surface of this inner-border tract is generally plane, but wells indicate that the underlying bedrock surface is very uneven, the depth to rock ranging from 20 feet or less to about 200 feet.

DISTRIBUTION OF ESKERS.

As already indicated, small eskers a fraction of a mile in length are found in many of the transverse depressions which characterize this morainic system from the vicinity of Hastings eastward across Eaton, Ingham, and Livingston counties. Other longer eskers or esker systems lead from the inner border district southward into the morainic system. These long eskers lie in valleys or troughs throughout much of their courses in the till plain as well as in the moraine. These valleys or troughs are in places nearly as narrow as the esker ridge, but commonly they are several times as wide. Some of the depressions are occupied for only a portion of their length by an esker; the association of esker ridge and trough is, however, so close as to render it probable that they owe their origin to the same agency—subglacial drainage. In a few places two eskers unite to form a single ridge. (See pp. 211-212.) All eskers of sufficient length are represented on the glacial map and will be considered in turn from Charlotte eastward. Eskers only a fraction of a mile in length will be passed over with a mere mention.

CHARLOTTE ESKER.

This esker, which has its terminus at the eastern edge of the city of Charlotte, is about 9 miles in length. Its northern end is in sec. 3, Benton Township, on the north side of the Thornapple River valley. The river passes across its line in the edge of secs. 10 and 15. The esker follows up the south fork of Thornapple River to the Grand Trunk Railway, about 11/2 miles southwest of Potterville. Thus far the esker is represented by short ridges separated by gaps nearly as long as the separate ridges, but from the railway southward, across sec. 34, Benton Township, it is more nearly continuous as a low winding ridge 15 to 20 feet in height and 90 to 100 yards in width at its base. A few short spurs lead from it to the border of the trough in which it lies. In Eaton Township it is well developed in the north part of sec. 4; for the next mile southward it is much interrupted; and after this it is again continuous for a mile or more. Its southern terminus is a well-defined fan-shaped sandy delta which covers about 3 square miles immediately east of Charlotte. Wells in this delta penetrate a fine gravel with much sand intermixed throughout its entire depth to the underlying sandstone. The sandstone has an uneven surface, the depth to it ranging from 16 to 60 feet.

Slight excavations in the esker near its north and south ends show it to be composed mainly of gravel of medium coarseness. The pebbles are largely sandstone of local derivation.

The well-defined trough, in which the esker lies from its head to its southern end, shows a slight descent to the Thornapple Valley and then a slight rise to the delta at Charlotte. At its lowest part its altitude is about 850 feet above sea level, and at the esker fan it is approximately 900 feet. Its depth is from 10 to 20 feet and its width from one-eighth to one-fourth mile. It passes entirely through the Charlotte morainic belt, the esker fan being at the outer edge of the moraine, and it is in the moraine except for 2 or 3 miles at its northern end, where it is in the inner border till plain.

MASON ESKER.

Investigation.—The Mason esker (see Pl. VIII), which passes through the city of Mason, the county seat of Ingham County, and the Williamston-Dansville esker (see Pl. IX), which lies a few miles farther east, were each described briefly by C. C. Douglas[1] in 1839, being among the first of this class of ridges to be described in North America. The Mason esker was also briefly described by L. C. Wooster[2] in 1884. The Mason and Charlotte eskers were studied by the writer in the fall of 1887, and the description here given of the Mason esker was prepared by him in the following winter but was never submitted for publication.

Extent.—The Mason esker is the longest yet observed in Michigan, its length being not less than 20 miles. Cemetery Hill, a prominent gravel knoll 2 miles southeast from the statehouse at Lansing, near the mouth of Sycamore Creek, may be regarded as its northern terminus. This hill rises about 60 feet above the bed of the creek on the west and 30 feet above the valley on the east; a few gravelly knolls to the east and northeast form an indefinite northward extension. Its southern terminus is in the Charlotte morainic system southeast of Mason. For its entire length it lies in a well-marked trough.

Esker trough.—For about 3 miles south from Cemetery Hill the esker follows a depression, one-fourth to one-half mile wide, in which Sycamore Creek flows. About 11/2 miles north of Holt, however, the creek bends abruptly, and the esker trough leaves the creek valley and remains distinct from it for 7 or 8 miles. The esker trough in places has a width of half a mile and a depth of 25 to 30 feet, but within the space of a mile it may contract to 100 to 150 yards or may become so shallow that it is difficult to trace. For about 5 miles it maintains a uniform course approximately S. 20° E., then changes abruptly to about S. 70° E., and so continues for 2 miles or more, when it reunites with the valley of Sycamore Creek. For 3 miles the united valley takes a course fluctuating between S. 20° E. and S. 30° E.; then it changes and runs S. 50°-70° E. to the Mud Creek valley at the inner border of the Charlotte system where it swings abruptly south and follows the creek to its source in the northeast part of Leslie Township (T. 1 N.; R. 1 W.). Its form changes with its trend, being deepest where it runs S. 20° E. and shallowest where it passes eastward to join the Sycamore Creek valley; it deepens again when combined with the Sycamore Creek valley but shallows in crossing over to Mud Creek.

[1]Second Ann. Rept. First Michigan Geol. Survey, 1839, p. 67.

[2]Kames near Lansing, Mich.: Science, vol. 3, 1884, p. 4.

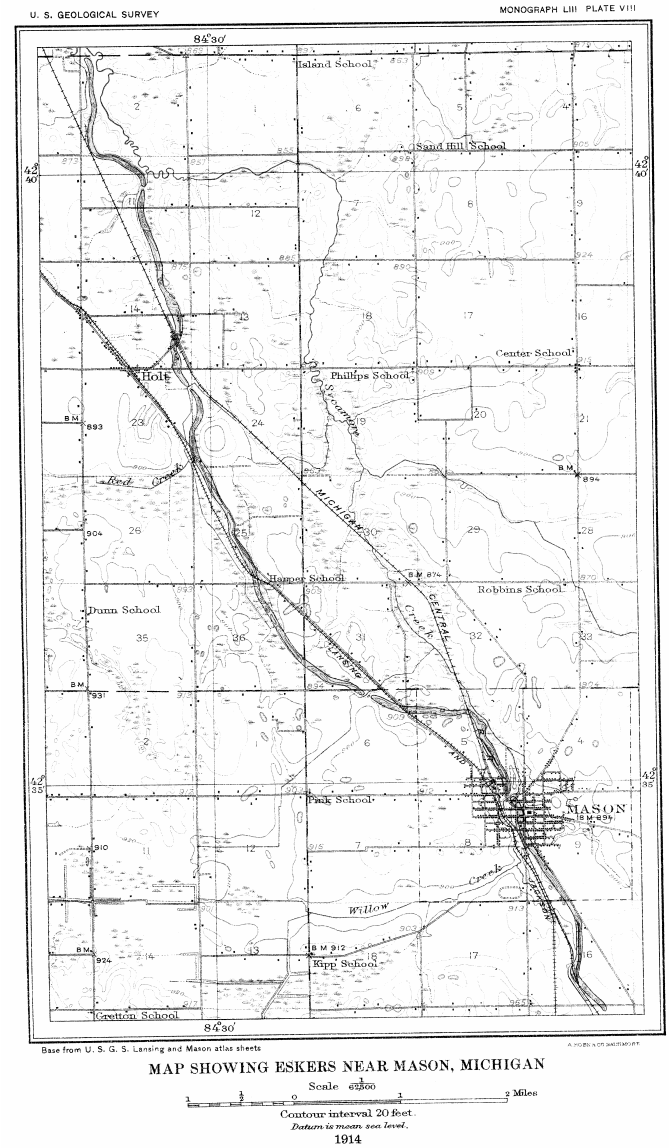
Topography.—In the first 3 miles of its course the esker consists of short ridges interrupted by longer gaps, one of which, 2 miles south of Cemetery Hill, gives passage to Sycamore Creek. Farther south, beyond the point where the esker trough reunites with the Sycamore Valley, the esker makes several abrupt turns but keeps within the limits of the valley. (See Pl. VIII.) Its interruptions are slight, apparently aggregating scarcely one-sixth of the combined length of the constituent ridges. The height of the ridges varies considerably and in places changes abruptly, dropping off in a few yards from 40 feet to less than 10 feet and even terminating abruptly to reappear within a few rods as a low ridge. On account of these abrupt breaks it has been used as a wagon road for but a short distance. Its width is only 50 to 100 yards even when highest, and its slopes are very steep, reaching 30° in places. The ridge is especially prominent where it makes the eastward deflection to come back to Sycamore Creek near Mason, its height being 20 to 30 feet above the bordering till plains. The esker passes directly through the city of Mason, where, for a short distance, it lies well up on the east slope of the valley, and rises above the bordering upland. For about 2 miles south of Mason it is 30 to 40 feet in height and practically continuous. After leaving Sycamore Creek in secs. 21 and 22, T. 2 N., R. 1 W.; it is low and interrupted by gaps for a mile or more, but on the swampy divide between Sycamore and Mud creeks it is broken by only narrow gaps. In the vicinity of the Charlotte morainic system it expands into a series of kames or plexus of ridges which inclose swampy depressions. Around the southern end of this kame plexus the moraine itself is exceptionally gravelly over an area of about 10 square miles, a feature which is perhaps due in part to the same subglacial drainage that produced the esker.

The course of the subglacial stream which formed the esker, as is shown by the bedding of the gravel, was from north to south, or the reverse of the present drainage, and the elevation of the esker trough increases in passing from the head southward, being about 830 feet near Lansing, 900 feet at Mason, 11 miles up Sycamore Creek, and about 915 feet at the southern terminus 7 or 8 miles farther south. It therefore ascends about 85 feet in less than 20 miles. If the gravelly portion of the moraine adjacent to the southern end of the esker trough be included the rise is 50 to 75 feet more, to the summits of the most prominent knolls. This rise is made abruptly, in places in less than one-half mile. It is doubtful if the stream which formed the esker and esker trough really made such an ascent. The esker trough seems likely to be a result of depletion of the basal portion of the ice by streams within the ice rather than beneath it. If so, the streams may have made little or no ascent.

Composition.—The esker, wherever opened, is composed of stratified and more or less perfectly assorted material. It gives evidence of the action of a stream which varied greatly in the rapidity of flow in different places along a given horizon, both longitudinally and from side to side, as well as at different horizons. The phenomena displayed are not unlike those found in the beds of existing streams flowing subaerially. The esker is evidently a stream-bed deposit, though probably deposited within ice walls.

The most extensive excavation is a railway gravel pit about a mile south of Mason. The esker here has a height of 35 to 40 feet and a breadth of only 50 to 75 yards at the base. The excavation is about one-fourth mile in length and passes obliquely through the esker, its southern end showing the structure of the east side and its northern of the west side, the main part of the exposure being in the elevated central portion. The eastern slope is underlain by fine sand but the main body of the ridge is of gravel. It has a capping of brown clayey gravel, varying in depth from a few inches on the crest to several feet on the less abrupt portions of the slope. The longitudinal vertical section shows that the beds both of the sand and the gravel have a nearly horizontal stratification, though they arch and sag slightly at intervals. Cross-bedding occurs only in thin beds and is not extensive. A transverse section near the southern end of the gravel pit shows evidence of gouging and subsequent refilling; the gravel beds break off suddenly on the east to a depth of 15 feet or more and are replaced by sand. In places the gravel has been taken away completely by the railway company and only a nearly perpendicular wall of sand remains. The sand beds dip rapidly toward the eastern edge of the ridge, but the gravel beds are nearly horizontal.

The coarse pebbles, cobbles, and bowlderets in this esker, as well as in others studied in Michigan, are mainly of local rock material, which here is a sandstone of Carboniferous age. The finer pebbles are less conspicuously local and embrace rocks of various classes. Increase in angularity is accompanied by decrease in size, large pebbles being well rounded and pebbles one-half inch or less in diameter more or less angular. Of 91 pebbles whose diameter averages less than one-half inch, 32 were of crystalline rocks, largely granites, and the remaining 59 were sandstone, limestone, and chert, principally of local derivation. Of 374 pebbles classified whose diameter averages less than one-fourth inch, 134 were of crystalline rooks and the remaining 240 of the same classes as those of the other group. Much significance is attached to the fact that the coarse pebbles are so largely of local derivation; for if, as some suppose, eskers were formed by superglacial streams, they would have contained less local material (this being for the most part beyond their reach), and the coarse rocks would be largely of granites and other distantly derived material which had been brought to the surface by ablation.



[Plate VIII. Map showing eskers near Mason, Mich]

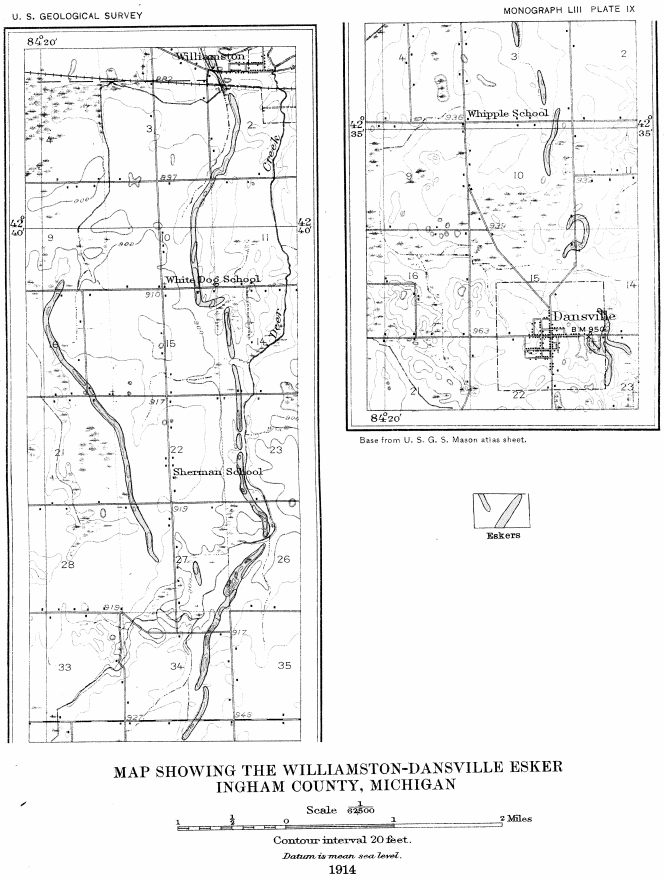
Several small gravel pits revealed features similar to those in the large pit. In some of them—for example, in the pit on the line of secs. 9 and 16, Vevay Township—the gravel beds showed a marked southward dip. In the pit at Holt station the beds dip perceptibly toward the eastern edge of the ridge.

In the plexus of ridges at the southern end of the esker more or less clay is mixed with the sand and gravel, and in places the material exposed appears to be partly assorted till. The flow of water seems to have been less vigorous than in the linear portion of the esker.

WILLIAMSTON-DANSVILLE ESKER SYSTEM.

The Williamston-Dansville esker system (see PI. IX) consists of a main chain of ridges leading from near Williamston, Ingham County, southward past Dansville, a distance of about 10 miles, and of two tributary chains of ridges, one leading southeastward from sec. 16, Wheatfield Township, to join the main chain at the Deer Creek valley in sec. 27, a distance of about 3 miles, and

the other following the valley of Doan Creek in a course west of south from sec. 19, Leroy Township, to sec. 23, Ingham Township, a distance of 8 miles. This last chain is interrupted by a gap of fully 2 miles in the northeast part of Ingham Township. A plexus of sharp gravel knolls is developed at the southern end of the esker system, which is at the northern edge of the Charlotte morainic system.



MAP SHOWING THE WILLIAMSTON-DANSVILLE ESKER
INGHAM COUNTY, MICHIGAN

Scale 1/62500
Miles
Contour interval 20 feet.
Datum is mean sea level.
1914

[Plate IX. Map showing the Williamston-Dansville esker, Ingham County, Mich]

A portion of this esker system, as already noted, was studied by C. C. Douglas[1] about 1839. The present writer studied the southern part in 1887 but did not trace out the esker system completely until the summer of 1900.

The main esker heads a mile west of Williamston near the south bluff of Cedar River in a prominent ridge 30 to 35 feet high. This follows the west side of the Deer Creek valley southward through sec. 2, Wheatfield Township, but takes a more direct course west of it in secs. 10 and 15. In the last two sections its general height is 15 to 25 feet, but in sec. 15 it consists only of a string of knolls broader than the ridge. For the next 2 miles it follows the Deer Creek valley along the line of secs. 22 and 23, 26 and 27, reaching a height of 50 feet in places in the second half of the distance. In sec. 34 it continues prominent, ascending about 30 feet from the creek valley to a till plain on the east, above which it rises 25 to 30 feet. In the south part of sec. 34 it descends into a swampy sag or esker trough and follows it past Dansville to the edge of the Charlotte morainic system, the border tracts are more undulating and bowldery from about a mile north of Dansville southward than they are farther north. As a rule; this main esker consists of a single string of ridges, but about a mile north of Dansville, where the main ridge curves to the east, describing nearly a half circle, small ridges run across the arc in line with the general course of the esker. Its height is from 15 to 30 feet in the vicinity of Dansville. In the plexus of knolls at the southern end of the esker points reach 50 to 75 feet above neighboring swamps. The knolls here contain some till as well as gravel, but the esker seems to be composed entirely of gravel and sand.

[1]Op. cit., p. 67.

The branch in Wheatfield Township lies in a till plain and is not accompanied by a trough or sag. It is exceptionally regular and smooth and has a height of 15 to 20 feet and rather steep sides. It has no delta at its southeast end, but terminates on the bluff of Deer Creek, one-half mile or more from the main esker. So far as exposed by gravel pits it shows a fine material, some parts being sandy, but most being coarse enough for road ballast.

The branch along Doan Creek has a few ridges strung along in secs. 19 and 30, Leroy, and secs. 25 and 36, Wheatfield townships, with only short interruptions. Then it is broken by a gap of over 2 miles, though the swampy esker trough persists. Near the center of sec. 13, Ingham Township, a ridge sets in and runs southwestward, with but slight breaks, for about 2 miles to the intersection of the main esker. In the last mile it is bulky and irregular, but elsewhere it is a low and narrow ridge and is of typical esker form. The best exposure is in a gravel pit in sec. 36, Wheatfield Township, where a ridge 30 feet high is opened from top to bottom and exposes gravel suitable for road ballast for its entire depth.

LEROY TOWNSHIP ESKER.

In Leroy Township, in eastern Ingham County, an esker about 5 miles long lies 2 to 21/2 miles east of the east branch of the Dansville esker and trends nearly parallel with it from north-northeast to south-southwest. It heads in the southwest part of sec. 15 and follows a small tributary of Doan Creek through secs. 21, 28, and 33, much of the way in a swampy sag. It has a general height of 12 to 15 feet and the steep slopes characteristic of the normal esker. Its continuation on the till plain in sec. 32, Leroy Township, and the north part of sec. 5, Whiteoak Township, is rather faint, but it reappears in strength in the southwest part of sec. 5 and runs across the corner of sec. 6 into sec. 7 to the border of the main moraine of the Charlotte system. In constitution this esker is more sandy than the Mason and Williamston-Dansville esker systems.

ESKER SYSTEM OF WESTERN LIVINGSTON AND EASTERN INGHAM COUNTIES.

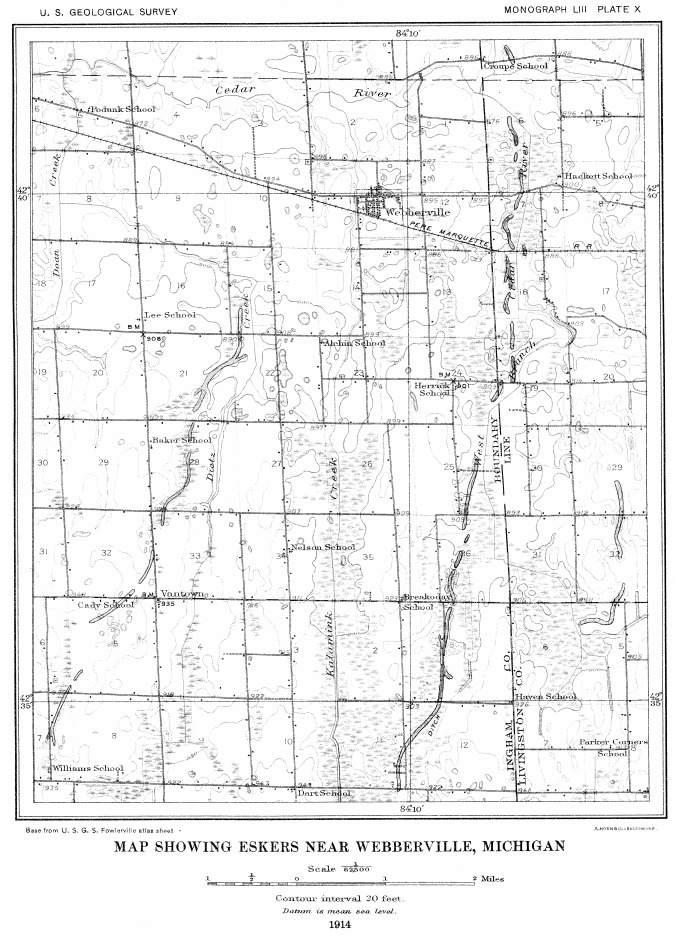
An esker system begins in the Cedar River valley in the southwest corner of Conway Town ship, Livingston County, and runs southward about 3 miles along the valley of the west branch of the Cedar one-fourth to one-half mile east of the Ingham-Livingston county line. (See Pl. X.) Its trough then bears west of south into the edge of Ingham County, but is devoid of esker ridges for about 11/2 miles. In sec. 25, Leroy Township, however, ridges set in which are nearly continuous for 3 miles, in secs. 25 and 36, Leroy, and secs. 1 and 11, Whiteoak townships, Ingham County, ending in the middle of the east edge of a large tamarack swamp. The swamp is about 7 miles long and three-fourths to 1 mile wide, extending from sec. 26, Leroy Township, southward across sec. 26, Whiteoak Township. It extends back into the main moraine of the Charlotte system a couple of miles, but seems to have no esker ridges in it, the main esker terminating a mile or more north of the moraine.

A single segment of the esker about 15 feet high and nearly one-half mile long lies north of Cedar River in a marshy tract just south of a moraine in sec. 31, Conway Township. A space of nearly a mile separates it from the next segment to the south in sec. 6, Handy Township. From sec. 6 to sec. 19, Handy Township, it is nearly continuous and has a height ranging from 5 to 40 feet. It is double for a short distance near the Pere Marquette Railroad and incloses a small basin. It does not follow the sag or esker trough, but lies between the trough and Cedar River on a till plain that stands about 20 feet above the river. The portion in Ingham County is in places double or even treble, ridges being nearly parallel to one another and separated by narrow swampy tracts. There are also slight offshoots in places, a few rods in length. The greatest complexity is found in sec. 1, Whiteoak Township. The height of the ridges ranges from 15 feet to about 40 feet.

The portion of the esker in Livingston County is of coarser material than that in Ingham County; in Livingston County cobble is in places mixed with the gravel, and in Ingham County sand is mingled with it.

IOSCO ESKER.

About 2 miles east of the southern part of the esker system just described a disjointed chain of short eskers leads west of south from sec. 29, Handy Township, to sec. 19, Iosco Township. The portions in secs. 29 and 32, Handy Township, are in the midst of an isolated tract of knolls that lies north of the Charlotte morainic system, its southern end being separated from the inner border of the moraine by a till plain over a mile in width. In sec. 5, Iosco Township, the esker runs out onto this till plain and is broken by a marshy gap about a mile in width. It reappears in sec. 7, Iosco Township, and continues as disjointed ridges as far south as sec. 19, where it terminates in the midst of the Charlotte morainic system with a small sandy expansion, possibly a delta.



[Plate X. Map showing eskers near Webberville, Mich]

OAK GROVE-HOWELL-CHILSON ESKER SYSTEM.

The Oak Grove-Howell-Chilson system is apparently a combination of two and possibly three eskers in an end-to-end series. (See Pl. XI.) The southernmost and probably the oldest leads from near Howell Junction or Ann Pere southward toward Chilson, but the depression in which it lies continues northward past Thompson Lake in the east part of Howell to the southern end of another well-defined esker which extends along the valley of Bogue Creek for 4 or 5 miles. Beyond a space of a mile or more along Bogue Creek is without esker ridges, but at Oak Grove a chain of esker ridges begins and is traceable northward for 2 miles.

The combined length of the series is 14 or 15 miles. The portion between Howell Junction and Chilson consists of disjointed ridges for about a mile, but from near the center of sec. 7, Genoa Township, a nearly continuous ridge extends to the east part of sec. 19. It is very winding in its course through sec. 18, but maintains a general trend about S. 20° E. Its height ranges from 10 to 20 feet and its width from 50 to 75 yards. Near its southern end a fanlike expansion plane, except for basins and surrounded by an extensive swamp a few feet lower, covers the southwest part of sec. 20. The swamp in turn is surrounded by prominent morainic hills, and the morainic topography extends north nearly to Howell along the east side of the esker. In the line of

continuation of this esker system, and possibly related to it, in the portion of the moraine west and southwest of Chilson, there is a chain of prominent kames, three of which reach 1,100 feet and a fourth 1,060 feet above sea level. The esker trough reaches 920 to 950 feet in the portion south of Ann Pere.

The esker along Bogue Creek has a fanlike expansion at its southern end, in sec. 25, Howell Township, where also it is developed into a plexus of ridges. With this exception it is generally a single ridge, though in parts of sec. 19, Oceola Township, it consists of two parallel ridges side by side. The sag or depression followed by the esker is swampy along much of its length, though in places Bogue Creek has cut down sufficiently to drain the swamp. This swamp is at the western edge of a complicated network of swamps that covers the western third of Oceola Township and appears to mark the lines of subglacial drainage in the plain north of the great interlobate moraine whose inner border comes up to Howell. These features are shown quite clearly on the Howell topographic sheet. Several exposures on the borders of these sloughs and swampy tracts show a thin deposit of till resting on sand and gravel and possibly consisting of englacial material deposited during the withdrawal of the ice and the contemporary deposition of the esker ridge.

Most of this esker along the Bogue Creek valley is not regular but is bead-shaped—bunched up in places connected by very weak, low ridges. Parts of it, however, in sec. 18, Oceola Township, form typical esker ridges 10 to 20 feet high. On the line between sec. 12, Howell Township, and sec. 7, Oceola Township, the ridge is 30 to 40 feet high and in places nearly one-eighth mile wide. In sec. 19 it is banked against the west side of the valley and rises 60 feet above the swamp on the east but only 10 to 15 feet above the plain on the west. The plexus of ridges and the bordering sandy plain in sec. 25, Howell Township, seem to form the natural terminus of this section of the esker.

The northern section near Oak Grove is complex in the vicinity of the Bogue Creek mill pond in the eastern part of the village, three ridges converging on the north side of the pond and one of them continuing southward along the east side and terminating without an esker fan at the north edge of a weak moraine. Esker ridges continue for 2 miles north of Oak Grove, but they are interrupted by wide gaps. The district, like that in western Oceola Township, is full of swampy channels which were probably lines of subglacial or glacial drainage.

HARTLAND ESKER.

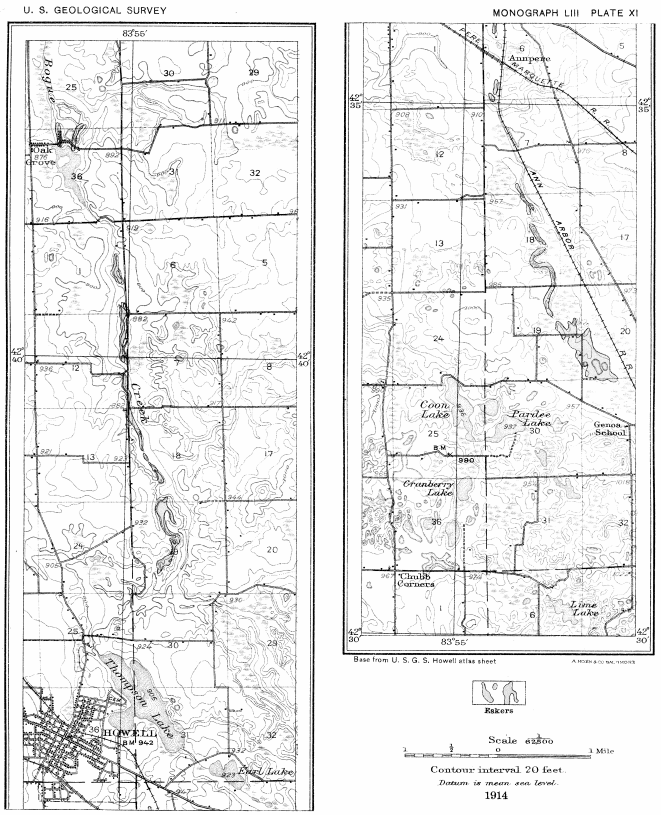
In the valley of North Ore Creek, in the vicinity of Hartland, in eastern Livingston County, a chain of short esker ridges leads southeast into the village of Hartland. This village stands on a plexus of esker-like ridges rising 25 to 40 feet above marshes in the valley, and on an esker fan or delta standing about 20 feet above the marshes. About a mile northwest of Hartland, near the center of sec. 8, a plexus of esker ridges rises 30 to 40 feet above the bordering marshes. The esker is developed in fragmentary form as far north as Parshallville, about 3 miles from Hartland. East of the esker lies a very prominent moraine and west of it a gently undulating till plain. Hartland stands at the southeast edge of the till plain in a recess in the moraine. The swampy depression, which continues from Hartland southeastward through the moraine, is probably a line of subglacial drainage.

PSEUDO-ESKERS.

In structure the eskers are commonly gravelly with thin beds or small inclusions of sand. Little till is present, though it occurs on a few of the slopes and partly caps some of the short esker-like ridges, as in secs. 30 and 31, Roxana Township, Eaton County. Some ridges have the form of eskers but are composed largely of till; thus, in secs. 24 and 25, Kalamo Township, Eaton County, there are winding ridges of esker type 20 to 30 feet in height and 100 yards or less in width, which have swampy depressions on each side as in the ordinary eskers, but which at an exposure where crossed by an east-west road show till to a depth of 10 to 15 feet. The tops of the ridges are about on a level with the bordering till plain, so that it is possible that they owe their origin to the erosion of the drift in the depressions along their sides rather than to building up by subglacial streams. Or it is possible that the entire topography, depressions as well as ridges, originated without the aid of subglacial drainage, and that the similarity to an esker is a mere accident. Such ridges were noted also in Delhi Township, Ingham County, one group being in secs. 29, 30, and 31 and another in secs. 34 and 35. The first group trends north-northeast and south-southwest and the second group northwest and southeast. The ridges are 15 to 20 feet high and as narrow as the ordinary esker and are bordered on each side by swampy depressions. Ridges of this class may perhaps be termed “pseudo-eskers” until their origin or relation to eskers is determined.

VALPARAISO MORAINIC SYSTEM OF THE LAKE MICHIGAN LOBE.

The Valparaiso morainic system, named from the city of Valparaiso, Ind., was described in Monograph XXXVIII from the Wisconsin-Illinois line around the southern end of Lake Michigan through northern Indiana and northward as far as Allegan County, Mich. The studies on which that description is based were made in 1887 and only a part of the region has been visited by the writer since that year. Studies, however, have been made northward on the east side of Lake Michigan far enough to determine the full extent and relations of the system in that district. These later studies, as indicated in the discussion of the Kalamazoo morainic system, have led to some changes in the interpretation of the relations of the Valparaiso system to the Kalamazoo.



MAP SHOWING ESKERS NEAR HOWELL, MICHIGAN

[Plate XI. Map showing eskers near Howell, Mich]

The present discussion is confined to the portion of the Valparaiso morainic system in Indiana and Michigan, there being no apparent necessity for revising the discussion of the Illinois portion in Monograph XXXVIII. The term “system” is used because the moraine consists in places of two or more constituent ridges. As these ridges interlock at short intervals they scarcely admit of separate discussion and scarcely merit individual names.

COURSE AND DISTRIBUTION.

The Valparaiso morainic system occupies and constitutes the high divide at the head of Lake Michigan, which separates the St. Lawrence from the Mississippi drainage. Its inner border is only 5 to 15 miles from the shore of the lake. Its width, including the small till plains between its constituent ridges, ranges from 5 to 20 miles, and its general width is 7 or 8 miles. It is one of the strongest morainic systems of the Lake Michigan ice lobe. The glacial maps (Pls. VI and VII, in pocket) show its variations in breadth and complexity, and it is here necessary to mention only a few details of its distribution.

In the vicinity of the State line of Illinois and Indiana there are at least three ridges in the system with well-defined crests, but they are so lapped upon one another that no intermorainic spaces occur. In passing eastward to the vicinity of Valparaiso the outer ridge dies out or becomes submerged in the great gravel plain south of the Valparaiso system. The middle and inner ridges are less distinct from Valparaiso eastward than toward the west, and in one place they merge in a single great ridge about 5 miles in width. They are blended or closely associated in Michigan as far northeast as St. Joseph River. East of St. Joseph River they form two prominent moraines separated by a narrow till plain, but farther east, near the line of Berrien and Van Buren counties, they coalesce into a single great belt which runs northeastward across Van Buren County to the Kalamazoo Valley in southern Allegan County. Outside of this great belt are the Kendall moraine and the weak ridges in eastern Van Buren and northwestern Kalamazoo counties (see p. 183) that seem to connect the Valparaiso with the Kalamazoo system. North of the Kalamazoo Valley two prominent moraines appear and continue separate to the southwestern part of Kent County, where the outer merges with the outer ridge of the Charlotte system of the Saginaw lobe; the inner, however, extends nearly to the outer ridge of the Lake Border morainic system. In western Kent and eastern Ottawa counties the association with the outer part of the Lake Border morainic system is so close that some difficulty is found in drawing a continuous line of separation; this, however, may follow a narrow depression that runs southwestward from Grand River to Jamestown and thence southward along Bear Creek to Rabbit River. North of Grand River the Valparaiso system probably includes a strong moraine that lies immediately west of Grand Rapids and extends northeastward into the bend of Rapid River near Rockford, where it connects with the correlative moraine of the Saginaw lobe. It may also include the strong moraine in northwestern Kent and southeastern Newaygo counties that correlates with the inner part of the Charlotte system, and may also include the west part of the interlobate tract in Mecosta and Osceola counties, though this, with the moraines bordering it on the west, may possibly be within the limits of the Lake Border system.

TOPOGRAPHY.

ALTITUDE.

Most of the inner border of the Valparaiso morainic system is between 75 and 100 feet above the level of Lake Michigan, or 655 to 680 feet above sea level, and has but little range in altitude. From it the surface rises at least 100 feet and in places 200 feet or more to the main crest of the morainic system. In Indiana the altitude of the crest ranges from about 750 feet in Lake County to nearly 900 feet in Laporte County, and in Michigan from 750 to 800 feet near St. Joseph River and northward across Van Buren County. The outlying Kendall moraine (p. 183) reaches an altitude of about 900 feet in the northeast township of Van Buren County. In Allegan County the range is from about 700 feet up to 900 feet. In southwestern Kent County Dias Hill, standing at the point where the moraines of the Saginaw and Lake Michigan lobes come together, reaches an

altitude of 1,032 feet and towers more than 100 feet above the neighboring moraine.

Along the outer border the altitude is generally much greater than on the inner border. The difference, however, is slight in the vicinity of the Illinois and Indiana line, where the altitude of the outer border is scarcely 700 feet. The altitude on this border reaches about 800 feet in the vicinity of Laporte, and is maintained eastward to St. Joseph County, Ind. It appears probable, however, that the portion from Laporte eastward (see p. 184) embraces an outwash apron of the Kalamazoo system, for lines of glacial drainage heading in the Valparaiso system are only 775 to 780 feet at their heads. The altitude is below 800 feet in the vicinity of the St. Joseph Valley, but is slightly above 800 in the interval between St. Joseph and Paw Paw rivers. It drops to 750 feet or less at Paw Paw River and remains below 800 feet from there to Kalamazoo River along the border of the Kendall moraine. Between the Kendall moraine and the main moraine to the west, however, an outwash apron stands at an altitude of about 800 feet. From the Kalamazoo Valley northward the outer border is generally slightly above 800 feet.

RELIEF.

The relief on the outer border is thus comparatively slight, being in few places more than 50 to 75 feet and in some places altogether lacking, the moraine scarcely rising to the level of the outwash apron. The relief on the inner border, however, is everywhere conspicuous, ranging from about 100 to 200 feet or more.

CHARACTER.

The morainic system presents great variations in topography, some portions being of a subdued swell and sag type with differences of only 10 to 30 feet between the swells and sags, and other portions being characterized by very sharp knobs among which are deep basins occupied by small lakes. The smoothest portion is found in the vicinity of the Illinois-Indiana line.

As already indicated, three ridges, closely associated and yet having distinct crests, form the morainic system in the vicinity of the Illinois-Indiana line. The northernmost is sufficiently prominent to constitute the divide between the Lake Michigan and the Kankakee River drainage, and yet on the whole is less conspicuous than the middle ridge; the southernmost is the least conspicuous of the three. The interruptions in the middle ridge are very slight, but those in the southern ridge are wide. The only conspicuous lake is Cedar Lake, which is situated about 6 miles southwest of Crown Point, at the head of a valley which leads southward into the Kankakee Marsh. It has an area of 1.17 square miles but is only 18 feet deep.[1]

To the east, in Porter and Laporte counties, Ind., the knolls are sharper and the moraine has great prominence on its inner border, rising in places 150 feet in less than 2 miles. Small lakes are numerous among the morainic knolls and in basins on the gravel plain just outside. From the Indiana-Michigan line northward the contours are commonly sharp, the knolls ranging from 15 to 60 and even to 80 feet in height. Several elevated tracts a few square miles in area rise above the general level of neighboring portions of the moraine; notable are those in Bainbridge Township, Berrien County; in central Lawrence, southern Arlington, and northern Bloomingdale townships, Van Buren County; in northwestern Trowbridge and northern Cheshire townships, Allegan County; and in a tract north of Allegan. Most of these have abrupt borders on two or more sides and a relief of 60 to 100 feet. The tract north of Allegan has an abrupt descent both on the north and the east, and that in Cheshire Township has the same on the north and the west. The tract in Arlington Township, with armlike projections into Hartford Township, has an abrupt border on all sides with a relief of 50 feet or more. The tract in Bainbridge Township has an abrupt border on the north and west and on portions of the east and south. Aside from the greater altitude, these tracts differ but little from the neighboring lower portions of the morainic system, for the latter bear usually sharp knolls and ridges.

[1]Determined by the members of the zoological department of the State University of Indiana.

Among the places where knobs rise 60 to 80 feet above border portions of the moraine may be mentioned Watson Township, Allegan County; the vicinity of Great Bear Lake in Van Buren County; a strip on the south side of Paw Paw River from near Lawrence nearly to Paw Paw, and several places along the eastern border of the morainic system in Berrien and Van Buren counties.

Swamps are very common among the morainic knolls in the Michigan portion, there being usually several in each township. Most of the lakes are small, few exceeding a square mile in area, though if the bordering swamps are included some of them cover 2 or 3 square miles. Lakes are especially conspicuous along the eastern border of the morainic system and in neighboring parts of its outwash gravel plain.

From northern Allegan County northward to Grand River the morainic tracts are traversed by lines of glacial drainage that break their continuity. The morainic system is also completely cut through by Rabbit River, a tributary of the Kalamazoo heading in northeastern Allegan County. The larger streams, Kalamazoo, Paw Paw, and St. Joseph rivers, all cut through the morainic system and each is bordered by broader terraces and has a valley wider than seems likely to have been produced by the postglacial drainage. The Kalamazoo, however, makes its passage in a rather narrow valley. The several valleys seem to have been utilized as lines of glacial drainage.[1]

STRUCTURE OF THE DRIFT.

THICKNESS.

Along the entire course of the Valparaiso morainic system in Indiana and Michigan the drift is very thick, probably averaging more than 200 feet, and few wells have reached the rock. The greatest thickness reported is at Laporte, where 295 feet of drift was found. Rock surface is in places only about 400 feet above sea level, and nowhere seems to reach 700 feet; it is known to rise above 600 feet only in northern Allegan County and in neighboring parts of Kent and Ottawa counties.

A considerable portion of the drift is probably of pre-Wisconsin age, but the records obtained do not afford as a rule criteria for separating the earlier from the later deposits. The thickness of the Wisconsin drift probably does not greatly exceed the measure of the outer border relief of the moraine except in places where the gravel filling on that border has been great. The gravel filling is of little consequence in northeastern Illinois and in Lake and Porter counties, Ind., but farther east and north it is of considerable depth. The relief in Illinois is estimated to average about 65 feet. The average thickness of the Wisconsin drift may be somewhat less than the relief since the moraine is lower and the drift probably thinner on the borders than along the main crest. In all probability the thickness of the Wisconsin drift is as great along the portion of this morainic system in southwestern Michigan as in northeastern Illinois.[2]

[1]For a detailed description of the portion of this morainic system in Allegan, Van Buren, and Berrien counties, Mich., see Mon. U. S. Geol-Survey, vol. 38, 1899, pp. 348-353.

[2]A list of 68 borings along the Valparaiso morainic system in northeastern Illinois, northwestern Indiana, and southwestern Michigan is presented in Mon. U. S. Geol. Survey, vol. 38, 1899, pp. 354-355.

COMPOSITION.

The drift shows interesting changes in structure along the course of the Valparaiso morainic system from Illinois into Indiana and Michigan. In Illinois the Wisconsin drift is mainly a blue clayey till similar to that forming a considerable part of the Wisconsin drift in Wisconsin. Eastward into Indiana till continues to predominate over sand and gravel only about to the meridian of Valparaiso, beyond which to the northeast sand and gravel greatly predominate over the till. The prominent portions of the morainic system appear to contain a larger proportion of sand and gravel than the lower areas, not only in Porter and Laporte counties, Ind., but also in Michigan; wells that penetrate nothing but sand and gravel for 100 feet or more are not uncommon, though most of them contain a little till. The marked differences are probably referable in part to drainage conditions attending the deposition of the drift and in part to original sandiness of the material embedded in the ice. Mr. Taylor[1] has called attention to the fact that the gravelly and sandy portion of the morainic system coincides in extent with the belt of prominent dunes along the shore of Lake Michigan and has suggested that the great abundance of sand in this portion of the moraine may be due to its blowing in from lake dunes during an interglacial interval. Probably, however, the principal factor has been the glacial drainage, which was exceptionally vigorous in the region. Furthermore, the sandy and gravelly character of the drift extends eastward over several counties in southern Michigan beyond the reach of the Lake Michigan dunes.

Well records setting forth the structure of the drift along this morainic system have already appeared in other publications.[2]

BOWLDERS.

Bowlders in moderate number strew the surface of the moraine, but are on the whole less abundant than in the Kalamazoo morainic system. The great majority are crystalline rocks of Canadian derivation 3 feet or less in diameter. A few immense bowlders of limestone and sandstone were noted in western Van Buren County.

In western Bangor Township sandstone bowlders are scattered over a tract about 11/2 miles from north to south and scarcely one-half mile in width, but are most abundant in secs. 16 and 17, and especially on a prominent knoll on the section line. One bowlder on this knoll supplied stone to build a large house in Hartford. Two others still remain, one measuring 24 by 21 by 21 feet on the sides, and the other 30 by 18 by 15 feet; each stands 6 or 8 feet above the surface and extends to an undetermined depth—one of them to at least 6 feet. Similar bowlders are scattered over Bloomingdale Township, in a belt nearly 3 miles in length and about one-fourth mile in width, extending from near the base line in sec. 4 south into sec. 17, about half a mile west of Bloomingdale station. They appear on the most prominent points along this line, but are scarce on the lowland between the knolls. They are embedded in the ground at various angles, some standing nearly on edge. The largest measure 15 to 20 feet and stand 6 to 8 feet above the surface. Similar large sandstone bowlders are reported from sec. 33, Bloomingdale Township, but were not visited by the writer. These sandstones are mainly red or pink or more rarely brown. They have some of the characteristics of the Potsdam sandstone, but their geologic horizon has not yet been fully settled.

A large limestone block in sec. 11, Hartford Township, had been uncovered at the time of the writer's visit over about 16 feet square and had been quarried to a depth of about 3 feet, yet neither its lateral limits nor its bottom had been reached. A bowlder of the same kind of limestone occurs on the base line between Bloomingdale and Cheshire townships less than a mile west of the north end of the sandstone bowlder belt above noted. It, however, is only about 5 feet cube. A large limestone bowlder in Van Buren County was examined by Alexander Winchell and was referred by him to the "Corniferous." Winchell supposed the bowlder to have been transported from the western end of Lake Erie, but the Erie ice movement can scarcely have extended to Van Buren County. It is more probable that

it was derived from ledges to the north of Van Buren County.

OUTWASH.

The drift is gravelly or sandy all along the outer border of the Valparaiso morainic system from its junction with the correlative moraine of the Saginaw lobe in southern Kent County, Mich., southward to the edge of the Kankakee Marsh in Porter County, Ind. Characteristic pitted plains, forming outwash aprons along a considerable part of the border, slope rapidly away toward the lower land along the inner border of the Kalamazoo morainic system. It is probable that the water after running across these outwash aprons formed long pools on the inner border of the Kalamazoo system connected by short, slightly channeled stretches, where the stream descended from one pool to another. In Indiana the drainage from the Valparaiso system seems to have been confined to broad, shallow valleys that lead across the high gravel plain (p. 180).

[1]Personal communication.

[2]For wells in Illinois and southwestern Michigan see Mon. U. S. Geol. Survey, vol. 38; for wells in northern Indiana see Water-Supply Paper U.S. Geol. Survey No. 21; for records of flowing wells in the lowlands among the morainic knolls and ridges of this system see Water-Supply Paper U. S. Geol. Survey No. 182.

DRAINAGE.

The drainage of the Valparaiso system can perhaps best be outlined from south to north, for the most southerly channels probably came into operation somewhat earlier than the more northerly.

From the meridian of Valparaiso westward streams which head as far back as the middle and even as the northernmost of the three ridges of that part of the system wind about through small valleys in which there is but little filling by deposits of gravel and sand connected with the retreat of the ice. This portion of the moraine, as already indicated, is clayey in constitution arid seems to have had a very weak outwash. The first stream east of Valparaiso, Crooked Creek, occupies one of the broad shallow valleys that leads across the large gravel plain of the upper Kankakee region. Between this valley and Laporte other streams lead across the gravel plain, but they are in small narrow valleys which evidently were not utilized to any great degree by drainage from the Valparaiso system. Little Kankakee River, which heads near the outer border of the Valparaiso system about 5 miles northeast of Laporte, is in a broad shallow valley that apparently received a line of drainage from the Valparaiso system; its bottom lands are covered with a rather fine sandy gravel not so coarse as that forming the bordering gravel plain and suggesting a rather weak drainage. Immediately east of New Carlisle a low plain of sandy gravel, known as Terre Coupee Prairie, heads in the Valparaiso system and leads southward to the Kankakee; its material is decidedly finer than that on the higher gravel plain to the west and thus suggests comparatively weak drainage. From Terre Coupee Prairie a narrow strip of sandy gravel extends northward to the bend of St. Joseph River at Buchanan and separates the Valparaiso system from the inner moraine of the Kalamazoo system. This strip is lower than the outwash apron on the eastern side of the inner moraine of the Kalamazoo system, and in places the stream that followed it has cut into the latter.

In the district between St. Joseph and Paw Paw rivers the Valparaiso system is bordered by an extensive gravel plain thickly set with basins near the edge of the moraine and sloping rapidly southeastward toward Dowagiac River. Its altitude is somewhat above 800 feet at the edge of the morainic system, but is only 760 to 775 feet in the vicinity of Dowagiac River. It is probable that at the time the weak ridge running from Paw Paw northeastward to the Kalamazoo system was occupied by the ice sheet the head of glacial drainage was immediately east of Paw Paw. The waters appear to have followed the swampy channel that leads from Paw Paw to the headwaters of the Dowagiac (see p. 184) and to have entered, near Dowagiac, at an altitude of about 720 feet, Lake Dowagiac, which extended as far south as South Bend, Ind., where it opened into the head of the Kankakee. This pool appears to have been a few feet lower than the line of glacial drainage from the bend of the Kalamazoo at Buchanan to Terre Coupee Prairie and was probably in the line of main discharge from the ice border between Buchanan and Paw Paw during the development of the extensive outwash apron.

Though the portion of the ice border between Paw Paw and Kalamazoo River east of the Kendall moraine and of its apparent weak correlative in northwestern Kalamazoo County has not so high an outwash apron as the portion between Paw Paw and Buchanan, yet it has along much of its length a narrow pitted plain standing a little below 750 feet at the southern end of the Kendall moraine and about 775 feet at the place where the weak moraine of northwestern Kalamazoo County joins the inner moraine of the Kalamazoo system. The district contains a swampy tract whose altitude is about 30 feet lower than that of the gravel plain; but this, as already indicated, was probably opened by a line of glacial drainage that discharged down the Paw Paw Valley instead of southward to the Kankakee. The outwash apron seems to be barely high enough to have been connected with the drainage to the Kankakee, for the swamp which leads southward from Paw Paw to Dowagiac is only about 750 feet in its highest part and has been filled to some extent by peaty accumulations.

If, as seems probable, the ice at the time the Kendall moraine was forming extended to the edge of the Kalamazoo system from Kalamazoo River northward, its drainage in the district north of the Kalamazoo is likely to have been in the same direction as it was during the development of the Kalamazoo system or southward past the site of the city of Kalamazoo to St. Joseph River.

As the ice shrank back from the inner border of the Kalamazoo system in the district north of Kalamazoo River it formed an extensive gravel plain thickly set with basins. This plain slopes eastward in the region west of Gun Lake and Gun River, but farther north in the reentrant angle between the moraines of the Saginaw and Lake Michigan lobes it slopes southward. Gravel appears at two distinct levels, a part of the outwash apron having been cut away to a depth of 30 or 40 feet by glacial drainage and a part remaining at the original level of filling. This lower plain has one arm extending northwestward from Gun Lake to a strong ridge of the Valparaiso system near Wayland and another arm extending northeastward to the moraine of the Saginaw lobe at Middleville. From the junction of these two arms the drainage is southward along the Gun River marsh to the Kalamazoo and thence along the marsh which connected the Kalamazoo with the Paw Paw along the eastern side of the Kendall moraine. The features suggest that at the time this lower plain was being developed the ice had withdrawn sufficiently from the lower course of Paw Paw River to permit drainage down its valley to the vicinity of Benton Harbor. At the time the higher or main outwash apron was being developed the drainage seems likely to have been southward to South Bend along the lines followed by the portions of the glacial drainage south of the Kalamazoo.

When the reentrant between the Lake Michigan and Saginaw lobes stood just north of Grand Rapids an outwash apron was developed in front of the Saginaw lobe on the east side of Grand River at an altitude of about 700 feet. An outwash apron along the front of the Lake Michigan lobe, south of Grand Rapids, in Wyoming and Byron townships, Kent County, has a similar altitude, being just below 700 feet, as shown by the Grand Rapids topographic sheet. The water evidently found escape southward between the two lobes past Grand Rapids, Carlisle, and Ross to Rabbit River near Dorr. The course beyond Dorr is less easy to interpret. Two courses are possible, and their relation to the drainage southward from Grand Rapids depends on the amount of recession that had been made by the Lake Michigan lobe at that time. If the ice still covered the strong moraine north of the city of Allegan and also the moraine southwest of that city the drainage is likely to have followed the line of a swampy depression utilized by the Lake Shore & Michigan Southern Railway from Dorr to Allegan, and then to have passed up the Kalamazoo Valley from Allegan to Otsego and turned southward into the Paw Paw drainage; to have taken this course, however, the waters must have passed over divides that rise a few feet above the 700-foot contour, or higher than the source of the glacial drainage near Grand Rapids. If, on the other hand, the ice had withdrawn from the prominent morainic tracts near Allegan the glacial drainage may have passed south westward between the ice border and these moraines into a local lake in the lower part of the Kalamazoo Valley. The drainage from Dorr into this lake came eventually if not at the beginning of the drainage southward from Grand Rapids. The indefiniteness of the correlations in different parts of the Valparaiso morainic system renders questions of this sort perplexing, and the full solution must depend upon the fuller correlations along the lines of the several members of the system.

The drainage from the reentrant between the Lake Michigan and Saginaw lobes in southeastern Newaygo, southwestern Mecosta, and western Montcalm counties is likely to have passed southward through the valley of Rapid River to its junction with the Grand River near Grand Rapids, and possibly it continued southward to Dorr along the line just discussed into Rabbit River. An outwash apron, developed on the east border of the Lake Michigan lobe in the southeast part of Newaygo County, slopes rapidly eastward away from the moraine. A few miles farther north, in the southwest corner of Mecosta County, an outwash apron of the Saginaw lobe slopes southwestward from the moraine in the district between Muskegon and Little Muskegon rivers. Whether the drainage from this northern outwash apron was southward through the western edge of Montcalm County or whether it followed down the Muskegon past the mouth of the Little Muskegon and then went southward past Rice Lake into the Rapid River valley depends on the amount of recession that had been made by the Lake Michigan lobe in southeastern Newaygo County.

CHAPTER X.
LATER MORAINES OF THE LAKE MICHIGAN, SAGINAW, AND HURON-ERIE LOBES.

LAKE BORDER MORAINIC SYSTEM OF LAKE MICHIGAN LOBE.

By FRANK LEVERETT.

COURSE AND DISTRIBUTION.

A complex group of moraines closely bordering the southern end of Lake Michigan was discussed in Monograph XXXVIII under the name Lake Border morainic system. This system has now been traced northward along the eastern side of the Lake Michigan basin, across the highlands between the northern part of Lake Michigan and Saginaw Bay, around the circuit of the Saginaw Basin to the “thumb” of Michigan, and southward through southeastern Michigan along the eastern slope of the “thumb.” In places, however, it is so intricately combined with earlier and later systems that its differentiation is not complete. The individual moraines of this system are still more difficult to trace around this entire circuit, for in some places they are bunched together and in others they are interrupted by gaps of considerable width.

Only in the southern part of the Lake Michigan basin is the Lake Border the innermost system; in the northern part later moraines which do not extend so far to the south lie within it. As far north as Holland the Lake Border system lies close to the shore of Lake Michigan, but from Holland northward to Oceana County it is 15 to 25 miles back from the shore. In Oceana County it returns to the shore and forms the prominent "clay banks" in the southwestern part of the county. From the vicinity of Hart northward it bears inland and is shut off from the lake by later moraines. It wraps around the northern part of the great interlobate moraine between the Lake Michigan and Saginaw lobes (see Pl. VII) and a little north of Cadillac bears away eastward. Within a short distance its southern or outer members turn southeast into the Saginaw basin, but its later members make longer circuits and run nearly to Lake Huron before doubling to the south. In Newaygo and Lake counties the Lake Border system banks against the earlier interlobate moraine to the east, but in Wexford and Missaukee counties it is quite distinct from the interlobate, and it remains so in its course southward along the west side of the Saginaw basin.

TOPOGRAPHY.

ALTITUDE.

The outer members of the Lake Border morainic system reach their greatest height immediately north and west of Cadillac, where they attain an altitude of 1,500 feet above sea level. The outermost ridge for 20 miles west from the line of Missaukee and Wexford counties stands above 1,400 feet. Beyond the turn to the south the ridge gradually declines in altitude, but a considerable portion of it is above 1,100 feet as far south as the latitude of Big Rapids and some points on it are above 1,300 feet as far south as the latitude of Baldwin. The ridges south of Muskegon River are scarcely 800 feet in altitude, the descent being very rapid from the great morainic mass north of Muskegon River to the slender moraines that lead away to the south. The decline becomes more gradual as the head of Lake Michigan is approached, but from the vicinity of South Haven southward to the head of the lake the ridges stand less than 700 feet above sea level.

In the great morainic mass which protrudes westward across Oceana County points within a few miles of the shore of Lake Michigan stand as high as 1,000 feet and large areas stand above 800 feet, or more than 200 feet above Lake Michigan.

The inner part of the morainic system is highest at the north a few miles south of Gaylord, where it touches the 1,400-foot contour. It declines steadily southwestward and keeps above the 1,300-foot contour to about the line of Antrim and Kalkaska counties, above the 1,200 to about the latitude of Kalkaska, and above the 1,100 to the line of Kalkaska and Grand Traverse counties. A few points in southern Grand Traverse County and on the moraine as far southwest as the bend of the Manistee in eastern Manistee County reach 1,000 feet. South of Manistee River most of the ridges on the inner border of this great system fall below 800 feet and part of the surface below 700 feet.

RELIEF.

On the outer border of the system in the vicinity of Cadillac the ridges have a relief of 50 to 100 feet or more above an outwash plain which covers much of southeastern Wexford County. The inner border relief of this portion of the system is 300 to 400 feet in Wexford County and about 300 feet in eastern Lake and northeastern Newaygo counties. The great morainic mass which runs westward from Newaygo County across Oceana County has a relief of 150 to 300 feet or more above the plains on its north and south borders. The slender moraines running southward from Muskegon River have a relief generally less than 100 feet, dropping to scarcely 50 feet as they near the head of the Lake Michigan basin; the inner or western moraines have generally considerable relief, but the outer ones rise very little above the eastern outwash plains.

CHARACTER.

The Lake Border morainic system has an exceptionally great variety of topographic expression, for it comprises the great ridges formed by convergence of ice movement and concentration of material at the north end of the peninsula, as well as the weak ridges formed where the ice was more free to spread out at the south end of the Lake Michigan basin. The rugged northern portion not only shows great relief, but parts of it north of Muskegon River have been cut by glacial drainage into an intricate network of prominent ridges and broad gravelly flats. The outer part, however, in eastern Newaygo and. Lake counties and southeastern Wexford County is almost unbroken by drainage gaps.

The ridges north of Muskegon River present a billowy surface with knolls 50 or even 100 feet in height, inclosing sags and basins. The ridges, which tend to parallel the trend of the morainic belt, become successively lower toward the inner or western part of the system.

The great morainic spur in Oceana and western Newaygo counties has a very billowy surface and great irregularity in height independent of the numerous gaps made by glacial drainage in the eastern part. The ice border seems to have shrunk across this morainic spur from east to west, and during the recession its escaping waters eroded the eastern part.

In the district between White and Muskegon rivers evidence is preserved of the recession of the ice border to the south of west. A billowy moraine leading southeastward from Hesperia to Newaygo has an outwash apron on the northeast and a till plain on the southwest. In Muskegon County this till plain includes a pitted gravel plain which is in places bowldery and seems to mark a receding ice border.

South from Muskegon River till ridges interrupted here and there by gaps in which sand plains occur, bearing low swells and shallow basins on their gentle slopes, extend all the way to the head of Lake Michigan. The basins and low plains were covered by the waters of Lake Chicago after the ice had disappeared.

STRUCTURE OF THE DRIFT.

THICKNESS.

On the borders of Lake Michigan the drift extends considerably below lake level, except in a few places such as the Waverly district near Holland and the New Troy district in Berrien County, where rock is reached a little above lake level. At Ludington and Manistee the drift extends below sea level, about 640 feet being present in some of the borings for salt on the low plain at these cities. Bedrock surface is only 300 to 400 feet above sea level along much of the eastern shore of Lake Michigan between Grand Haven and Grand Traverse Bay, and is generally less than 500 feet above in the district south of Grand Haven, as may be seen by reference to the map of rock contours (PI. II). The altitude of the rock surface inland from the lake is known at very few places, but it probably nowhere much exceeds 800 feet above sea level in the northern end of the southern peninsula. Its maximum height may be attained in the northern part near Gaylord, but it is very doubtful if it is held beneath the highest part of the morainic system in Wexford, Lake, and Newaygo counties; more probably the rock there is as low as the level of Lake Michigan. Such being the case, the drift on these high ridges is 700 to 1,000 feet or more in thickness and it probably averages over 500 feet from the vicinity of Gay-lord to Newaygo. From Newaygo to the head of the lake the average thickness is probably not far from 200 feet, the altitude of this district being comparatively low and the rock surface somewhat higher than in the district to the north.

The drift is probably in large part pre-Wisconsin in age, but data are not numerous that bear upon the separation between the Wisconsin and pre-Wisconsin deposits. Records of flowing wells in the district about 4 miles southwest of Shelby in Oceana County indicate the presence of peat or black muck at a depth of 175 to 200 feet (75 to 100 feet below the surface of Lake Michigan), and this seems likely to mark the separation between the Wisconsin and pre-Wisconsin drift. The wells were continued only to the bed of sand or gravel which immediately underlies the black muck. One well penetrated 15 feet of muck and two others nearly as much. The older drift beneath the muck is likely to be fully as thick as the younger drift above, for a well at Shelby, 4 miles away, on ground only about 100 feet higher than at these wells, penetrated 500 feet of drift.

COMPOSITION.

Along the entire length of the rugged portion of the Lake Border morainic system wells ordinarily pass through a large amount of loose-textured sandy or gravelly drift. In places this material is thinly capped with till but is thickly set with bowlders; in many other places it is sandy from the soil down to the bottom of the wells, most of which require curbing while in process of excavation. Bowlders are conspicuous on the prominent ridges from Oceana County northward. Large limestone blocks also occur; some of these in Oceana County were burned for lime in the early days of settlement, and led to the incorrect inference that limestone ledges are present in that county. Wells, however, indicate that the rock surface lies nearly 300 feet below the surface of Lake Michigan. Calcareous material, which is found in considerable abundance in the loose-textured drift deposits of the region, as noted many years ago by R. C. Kedzie while analyzing soils from that part of the State,[1] gives the soil great fertility.

From Muskegon River southward to the head of Lake Michigan the ridges of this morainic system are composed largely of grayish-blue clayey till. In some places the till contains only a few small pebbles, and in others it is laminated, indicating that it was water-laid. The crests of the ridges, however, seem to be land laid. Exposures of the laminated material may be seen here and there along the bluffs of Lake Michigan from Kalamazoo River southward.

Bowlders are found in moderate number along these till ridges but are less numerous than on the rugged portion of the morainic system farther north. They are chiefly of granite, though other kinds of rock are present. Large bowlders of reddish sandstone, similar to those on the Valparaiso morainic system near Bloomingdale and near Bangor, were noted on the crest of one of these till ridges in western Allegan County.

[1]Ann. Repts. Michigan Board of Agriculture for 1878, 1887, 1888, and 1893.

The plains bordering the moraines show the same changes as the moraines in passing from north to south, those in the northern portion where the ridges are sandy and gravelly being underlain by sandy material, and those in the southern portion bordering the till ridges being underlain by clayey material. In a few places, as between Muskegon and Grand rivers, a thin outwash of sandy gravel, derived from the ice border during the development of the till ridges covers the till.[1]

GLACIAL DRAINAGE.

LINES OF DISCHARGE.

Reference has already been made (p. 223) to the numerous lines of glacial drainage developed in connection with the recession of the ice border from the outer to the inner members of the Lake Border morainic system. In most areas the lines of discharge for the glacial waters are very clearly shown. The most elevated outwash tract is found just north and west of Cadillac, where about 100 square miles, standing at an altitude of 1,300 to 1,350 feet, was coated with sand and gravel by streams issuing from the outer moraine. Clam

River, a tributary of Muskegon River, heads in this plain and, with the Muskegon, probably carried the glacial waters to just above Newaygo, where they were deflected by ice to a well-defined channel that leads southward past Rice Lake to Rapid River, a tributary of Grand River. From Grand River near Grand Rapids the glacial waters made their way southward along the edge of the ice through narrow lakes to the incipient Lake Chicago at the head of the Lake Michigan basin and thence down the Chicago outlet.

As a rule the outwash in all the lines of glacial drainage connected with the Lake Border system is a rather fine sandy material.

GLACIAL LAKES.

Distribution.—During much of the time when the Lake Border morainic system was forming the area now covered by Lake Michigan was occupied by ice, and the drainage of western Michigan was forced to follow the eastern edge of the ice sheet southward to the southern end of the basin, where it found discharge through the Chicago outlet into the Desplaines Valley and thence to the Illinois and Mississippi valleys and the Gulf of Mexico. At that time the eastern tributaries, which now lead through the Lake Border morainic system directly to Lake Michigan, seem to have flowed south through a series of small glacial lakes that occupied the lowest available ground outside the ice sheet. In the early part of the development of the system, while the ice still covered the moraine north of Rabbit River in northern Allegan County, the northernmost lake in the series was apparently one that occupied the lower Kalamazoo Valley and received drainage from districts farther north through rivers whose courses lay outside the edge of the ice sheet. Grand River discharged into this lake along the abandoned channel that runs southward from Grand Rapids past Ross to Rabbit River. In the course of development Muskegon River also found its way to Grand River at Grand Rapids through a valley leading past Rice Lake to Rouge River, a tributary of Grand River heading in southern Newaygo County. Later, when the ice border was close to Lake Michigan near Holland, more or less ponding probably took place on the lower courses of White, Muskegon, and Grand rivers and a nearly continuous lake probably extended along the edge of the Lake Michigan basin from near Holland to the Chicago outlet.

The small lakes along the edge of the ice in southwestern Michigan did not form beaches of sufficient definiteness to permit easy mapping. The levels at which they stood can, however, generally be determined by the deltas of their large affluents and by the height of their outlet channels. The series of lakes and connecting channels was so complicated that the writer did not attempt to map them completely but simply determined the general extent and approximate level of each lake and its probable course of discharge to the next. When topographic maps have been made it will not be difficult to represent these lakes more definitely.

[1]For further details of the drift structure see Mon. U. S. Geol. Survey, vol. 38, and Water-Supply Papers U. S. Geol. Survey Nos. 21, 182, and 183.

Lake on the lower Kalamazoo.—The glacial lake that occupied the lower Kalamazoo covered much of the space between the Lake Border and Valparaiso morainic systems from Rabbit River southward into the Black River drainage basin in northwestern Van Buren County. Its northern limits were determined by the strong morainic ridge that lies north of Rabbit River in northern Allegan County. Several fines of evidence unite in fixing its altitude at about 680 feet; the sandy plain that now occupies its bed is definitely limited on the east and south by the Valparaiso system at an altitude of very nearly 680 feet, as shown by the railway elevations at Dunning and at Columbia and Grand Junction, and is bordered by a well-defined terrace of the Kalamazoo Valley at about 680 feet; further, the altitude of an outwash apron of the Lake Border morainic system near Fennville is about 680 feet. This lake appears to have at first discharged southward to Paw Paw River past Breedsville and Bangor and through swampy channels near McDonald, coming to the Paw Paw Valley near Hartford; but when the ice had shrunk back to Covert Ridge[1] the lake may have discharged along the eastern edge of the ridge, which is bordered by a somewhat sandy plain. The relative elevations of the two courses of discharge are not known, but they certainly differ by only a few feet.

The pitted gravel plain near Fennville occupies an area of several square miles along the outer border of Covert Ridge. Close to the ridge basins are conspicuous and the gravel is of medium coarseness; a mile or two outside the basins disappear and the gravel gives place to sand. The border of the glacial lake probably lay along the eastern edge of the basins. Small strips of gravel plain, preserved along the south edge of the moraine north of Rabbit River, lie at an altitude high enough to have been deposited outside of or above the edge of the glacial lake. The material is decidedly coarser than that on the sandy plain to the south.

Lake in lower St. Joseph and Paw Paw valleys.—The next lake in the series stands in the lower St. Joseph and Paw Paw valleys in Berrien County. This lake appears to have extended up the Paw Paw Valley about to Hartford and to have there received the drainage of the lake in the Kalamazoo basin. It filled in the narrow space between the Lake Border and Valparaiso systems from near Hartford southward about to Baroda, 10 miles south of St. Joseph, and crossed the divide between the St. Joseph and Galien river systems through a swamp south of Baroda. The altitude of this lake appears to have been about 20 feet lower than that of the lake in the Kalamazoo basin, as determined by the level of the outlet near Baroda and by a terrace on the St. Joseph near Berrien Springs which seems to be correlated with this lake and which stands about 660 feet above sea level. The outlet of this lake cuts into the edge of the part of the Valparaiso system directly east of Baroda and appears also to have cut slightly along the east edge of

the outer ridge of the Lake Border morainic system west of Baroda. These cut banks are, by hand level from Baroda, 20 feet higher than the station, or 660 feet. The area occupied by the Jake in the Paw Paw and St. Joseph valleys has a coating of gravel and sand several feet in depth, in places overlying a pebbleless silt. Whether the silt is to be correlated with this small lake and the overlying gravel and sand with Lake Chicago which afterward came into the same district can not at present be stated. Probably, however, the streams draining into the larger and longer-lived lake contributed a considerable part of the sand and gravel.

Lake on Galien River.—A pool 1 to 3 miles wide appears to have occupied the lower courses of the tributaries of Galien River in southern Berrien County, extending from the vicinity of New Troy southward about to the State fine and covering the western part of the space between the outer ridge of the Lake Border morainic system and the inner edge of the Valparaiso system. The soil in the areas supposed to have been covered by this pool is more sandy than that on a till plain lying nearer the inner border of the Valparaiso morainic system. After the ice had withdrawn from the outer ridge to the second ridge this pool spread into the narrow strip lying between the two ridges in southern Berrien County and the neighboring part of Laporte County, Ind., but does not appear to have been markedly lowered.

[1]This name was applied in Mon. U. S. Geol. Survey, vol. 38, to the principal till ridge of the Lake Border morainic system.

Lake on Trail Creek.—From the south end of the pool on Galien River the waters passed across a low divide to a pool in the lower course of the two forks of Trail Creek east and south of Michigan City, Ind., and from this pool to Little Calumet River, and thence into a small lake that extended from near Chesterton, Ind., to the Chicago outlet. The drainage from the lake on the St. Joseph descended only 20 feet to the Calumet Valley near Chesterton, and this descent was apparently made in the short passages from one pool to another. Sand is found along much of the course of this drainage but is perhaps in part due to deposition from the receding ice sheet as it melted back from the Valparaiso to the Lake Border morainic system; some of it, however, was probably deposited by this drainage.

Incipient Lake Chicago.—The lake at the south end of the Lake Michigan basin should, perhaps, be termed the incipient Lake Chicago, for it developed into that lake and had the same level and the same outlet. Its level was about 60 feet above Lake Michigan, or 640 feet above tide. As its southern limits are the same as those of the highest or Glenwood stage of Lake Chicago, the description of the border of the Glenwood beach given in Monograph XXXVIII applies to the border of this lake from near Chesterton to the Chicago outlet; the smaller lake, however, probably contributed but a small part of the beach material of this highest stage of Lake Chicago. This small lake expanded northward as the ice receded; in the early days of the Lake Border morainic system it stood entirely outside the limits of Lake Michigan, but by the time the till ridge south of Holland had been formed it probably extended some miles over the bed of the southern end of Lake Michigan. A considerable part of the district occupied by this lake is coated heavily with sand and sandy gravel, much of which seems referable to currents in the later and more expanded lake, but some of which may have been deposited earlier, during the recession of the ice from the Valparaiso to the Lake Border morainic system.

Wisconsin and Illinois drainage.—In southern Wisconsin and northern Illinois the lines of glacial drainage are traceable on the topographic maps from Milwaukee southward to Des Plaines River and to the Chicago outlet. There appears, therefore, to have been no marked ponding of the waters along the ice front on the Wisconsin side of the Lake Michigan basin.

LATE GLACIAL DRAINAGE.

In the later stages of the development of the Lake Border morainic system considerable ponding took place farther north than the Kalamazoo Valley and was apparently maintained until the ice border had receded from the morainic ridges near Holland sufficiently to allow free communication west of them to the somewhat expanded Lake Chicago. During the occupancy and development of the portion of Covert Ridge north of Kalamazoo River, the drainage apparently made its way by streams and small lakes into the glacial lake on the Kalamazoo. But when the ice border had receded to the westernmost of the till ridges in Ottawa County the water apparently found its way along the ice border to the vicinity of Holland and there entered Lake Chicago.

At one time during the recession of the ice border the Muskegon, which received drainage from the Lake Michigan lobe on the west and from the Saginaw Bay lobe on the east, ran southward past Rice Lake in southeastern Newaygo County, its altitude near Rice Lake being about 800 feet above sea level. It followed Rouge River to its junction with Grand River near Grand Rapids and probably continued southward (for a time at least), leaving the Grand River valley at the south edge of Grand Rapids and traversing a valley which leads past Ross to Rabbit River and thence into the lake in the lower part of the Kalamazoo. The altitude of the abandoned valley that runs south from Grand Rapids, as shown by the Grand Rapids topographic sheet, is somewhat less than 700 feet, or fully 100 feet below the channel in Newaygo County, where the Muskegon waters passed Rice Lake into the Grand River drainage. There probably was some ponding of waters along the Rouge Valley, but the valley is comparatively narrow and the ponded water would be considered a river pool rather than a lake.

The discharge from Grand Rapids southward to Rabbit River probably continued until the ice border had withdrawn to the vicinity of Jamestown, when a passage was opened past that village into the lake on the lower Kalamazoo. Aneroid readings indicate that the altitude

of the Jamestown channel was very nearly the same as that of the Ross channel, each being apparently between 680 and 700 feet at the present water partings in these channels. The Jamestown channel is very much smaller than the Ross channel, being about one-eighth mile wide, whereas the Ross channel is about one-half mile. It may, therefore, have carried only a portion of the glacial drainage, in which case the Ross channel continued in operation until a lower outlet farther west became available.

A small glacial lake seems to have been present southeast of Holland at an altitude higher than either the Ross or the Jamestown channel. The lake stood between the large morainic ridge north of Rabbit River and the smaller ridge immediately south and east of Holland. The southern shore of the lake is marked by a definite sandy ridge that passes through Fillmore and Overisel along the inner slope of the morainic ridge. Its altitude is about 120 feet above Lake Michigan, or 700 feet above sea level. The sand ridge corresponds pretty closely in altitude to a narrow sag or depression east of Drenth, which leads across the divide between Black River and Bear Creek and which seems likely to have served as an outlet for this small lake into the Bear Creek valley and thence, by a descent of about 20 feet, to the lake on the lower Kalamazoo. The sand ridge on the border of this small lake was mentioned in Monograph XXXVIII as a possible high shore of Lake Chicago, but further studies in that region have led to the abandonment of this interpretation.

North of Grand River in eastern Ottawa County narrow sags between the morainic ridges are filled to some extent by sand and gravel that was probably deposited in part as outwash during the development of the morainic ridges and in part as glacial drainage from districts to the north. The sandy strip east of the eastern of the two till ridges in the region heads in the valley of East Crockery Creek, but leaves that valley near Conklin and passes to the Sand Creek valley, through which it continues to the Grand River valley. Its altitude at Conklin is very nearly 700 feet, or sufficiently high to have thrown the discharge past either Ross or Jamestown, in case no lower passage toward the west was available.

The sag between the two till ridges of northeastern Ottawa County appears to have been utilized by the glacial drainage from West Crockery Creek, the glacial stream having left the Crockery Creek valley near the Muskegon-Ottawa county line. It was probably also utilized by the drainage from a small glacial lake that occupied a sand plain on the borders of the Muskegon Valley, a few miles east of Muskegon, there being a swampy channel just north of Ravenna that afforded a passage from this sandy plain into the Crockery Creek drainage. This swampy channel is at about the level of the fiat sandy tracts, or very nearly 690 feet above sea level, as indicated by railway stations at Mooreland and Twin Lakes.

It is probable that an outlet directly into Lake Michigan near Holland had been opened by the time the westernmost till ridge in Ottawa County was formed. The altitude of the waters on the east side of the till ridge would be likely to be governed by the height of the ground (about 680 feet) on the east side of the western till ridge immediately north of Zeeland.

REENTRANT DISTRICT BETWEEN THE SAGINAW AND LAKE MICHIGAN LOBES.

By FRANK LEVERETT,

In the discussion of the Kalamazoo and Valparaiso morainic systems of the Lake Michigan lobe the interlobate moraine between the Lake Michigan and Saginaw lobes was shown to extend northward to Cadillac. The present discussion aims to bring out the leading features in the reentrant district from the vicinity of Cadillac northward and eastward to the valleys of Manistee and Au Sable rivers. In this reentrant district the recession of the ice border, which was more pronounced than in neighboring parts of either of the lobes, formed several ridges and groups of knolls, which will be considered in order from older to younger.

HARRISON-LAKE CITY RIDGED BELT.

The most conspicuous chain of ridges in the district is one that leaves the West Branch morainic system of the Saginaw lobe immediately east of Harrison and runs northwestward through central Missaukee County to the correlative moraine of the Lake Michigan lobe in Wexford County. It is a narrow but sharply ridged belt with an average width of scarcely 2 miles and relief of 75 to 150 feet. Its highest part is directly north of Cadillac, where it rises slightly above the 1,500-foot contour. In Wexford County much of it rises above the 1,400-foot contour, but in Missaukee County it exceeds 1,400 feet only in the northwest part. From Lake City southeastward only a small part of the crest reaches 1,300 feet, much of it being about 1,200 feet. Narrow gaps 1 to 2 miles wide, in which no traces of the moraines can be seen, are utilized by drainage, one, near the corner of Roscommon, Missaukee, and Clare counties, by Muskegon River, and two, in Missaukee County, by small tributaries of the Muskegon. The ridged belt is thickly set with basins 10 to 50 feet deep and with knolls of corresponding height, so that its surface is about as irregular as that of the interlobate moraine elsewhere. The drift is gravelly and bowlders are not conspicuous. The soil is so much lighter than that of bordering till plains that scarcely any of the ridge has been converted into farm land; however, it once carried a heavy growth of white and Norway pine and hemlock and is well adapted for reforestation.

In Clare County the ridged belt is bordered on each side by sandy plains which once bore Norway pine. In southeastern Missaukee County it is bordered by till plains with rich soil. In northwestern Missaukee County it is largely bordered by sandy plains, though on the

north slope, in the western tier of townships of the county, it shows some rather clayey till. In Wexford County it is generally bordered by sandy plains.

Flowing wells are obtained in a gap in the ridged belt at Dolph, in eastern Missaukee County, at depths of 35 to 40 feet. They are reported to pass through "blue clay and putty sand" and to obtain water in sand. Shallow flowing wells 25 to 40 feet deep are also obtained in southern Missaukee County on the till plain west of the ridged belt, there being several in the vicinity of McBain.

The outwash from this ridged belt (see Pl. VII) was southward to the vicinity of Clam River and Clam Lake across the plain lying west of Cadillac. Similar southward outwash to Clam River led across a pitted plain west of Lake City. A short distance east of Lake City a narrow line of glacial drainage passed southeastward to Clam River, and a few miles farther east another somewhat broader line led southward to the same stream. The Clare County portion discharged directly into the Muskegon Valley. The entire outwash both in the out-wash aprons and the narrow lines of glacial drainage is a very sandy gravel.

HOUGHTON LAKE CHAIN OF RIDGES.

A weaker and more fragmentary chain of ridges than the Harrison-Lake City belt runs about parallel with it across southwestern Roscommon and northeastern Missaukee counties. It does not make complete connection at the southeast end with the West Branch morainic system of the Saginaw lobe though the southeast end of one of its ridges south of Houghton Lake comes within 3 miles of a projection or spur of the latter system. The ridge south of Houghton Lake has a relief of 60 to 100 feet above the lake and is one-half to 11/2 miles wide. It becomes weak west of the lake and is entirely wanting for about 5 miles west of Muskegon River. It is then about as prominent for 5 or 6 miles as on the south side of the lake, beyond which to a strong moraine on the south bluff of Manistee River it is represented only by scattered knolls. This chain of ridges and knolls is largely of gravelly drift, clayey till being noted only near the western end of the ridge south of Houghton Lake. Bowlders occur in moderate number, but are generally inconspicuous. The greater part of the ridge may not make valuable farm land, but it bears some good farms southwest of Houghton Lake. The plains immediately bordering this chain of ridges are sandy except in the vicinity of the west end of Houghton Lake, where there is some clayey till. Much of the bordering district is marshy.

A flowing well on a marsh near the outlet of Houghton Lake is 50 feet deep, largely through blue clay.

The glacial drainage from the Houghton Lake chain of ridges was evidently down the Muskegon Valley, for the ridges lie in a sandy plain that extends to the river in southeastern Missaukee and southwestern Roscommon counties.

HIGGINS LAKE SYSTEM OF RIDGES.

Higgins Lake lies between two morainic ridges, each of which is several miles in length. West of the lake the ridges seem to be represented by only a single belt, and east or southeast of it by isolated groups of drift knolls, surrounded by marshy plains that extend to the West Branch morainic system near St. Helen Lake, in eastern Roscommon County. The ridge on the south side of Higgins Lake, if a chain of hills east of the outlet is included, is about 15 miles long and is 1 to 11/2 miles wide; it stands 50 to 75 feet above the level of the lake and has a gently undulating surface. The ridge on the north side of the lake is about 16 miles long and less than a mile wide; it sets in at the southeast immediately south of Roscommon village, leads north of west into Crawford County, and then westward through the southern tier of sections to the southwest corner of the county. It there connects with a prominent drift mass covering several square miles in the northeast corner of Missaukee and southeast corner of Kalkaska counties that rises fully 100 feet above the bordering plains and more than 1,300 feet above sea level. The slender ridge that leads from this drift mass eastward to Roscommon has a relief of only 30 to 50 feet and rises but little above the 1,200-foot contour. The knolls southeast from Higgins Lake rise 50 to 75 feet or more above bordering plains. The chain of knolls known as Ninemile Hills and the knolls west and south of St. Helen Lake form a natural continuation of the southern ridge; knolls farther north are probably to be considered a continuation of the northern ridge. The relief above the bordering swamps puts these knolls above the reach of killing frosts in the late spring and some of them bear successful peach orchards. All these knolls and ridges are of loose and generally of gravelly drift containing enough fine-textured material to make them fairly fertile, and they are already largely under cultivation.

The plain bordering these knolls southeast from Higgins Lake and between Higgins and Houghton lakes is reported to have a clay subsoil. The drier parts are under cultivation, but a considerable portion is still covered to a slight depth with water in rainy seasons. East from Roscommon for a few miles and thence southeast to St. Helen Lake a sandy plain borders the clusters of knolls, but the northeast part of Roscommon County is occupied by a fertile till plain. A sandy plain west of Higgins Lake extends southward to the Muskegon River marshes in western Roscommon County.

This system of ridges is distributed along the divide between the Muskegon and Au Sable drainage, the southern border being drained to the Muskegon and the northern to the Au Sable. The glacial waters evidently found their escape down the Muskegon. The outwash, however, seems not to have been carried far from the edges of the ridges, probably because the district to the south has very little fall.

RIDGES SOUTH OF AU SABLE AND MANISTEE VALLEYS.

A somewhat complex series of morainic ridges runs along the south side of the Au Sable Valley from northern Ogemaw and southern Oscoda counties westward across southern Crawford County to the vicinity of Portage Lake; farther west it is continued by a massive moraine running along the south side of Manistee River from Portage Lake westward across southeastern Kalkaska, northwestern Missaukee, and northern Wexford counties.

The outer ridge of, this series is a distinct member for 35 or 40 miles. It parts from the West Branch morainic system about 10 miles north of West Branch and 3 miles directly west of Rose City. Instead of turning eastward with the West, Branch system it runs northward nearly to the line of Ogemaw and Oscoda counties and there turns abruptly westward. It passes across the southern edge of the southwestern township of Oscoda County and just north of the Roscommon-Crawford county line for about 9 miles. It makes a slight offset to the north at the valley of South Fork of Au Sable River but continues westward through southern Crawford County 21/2 to 41/2 miles from the south line of the county. Knolls in southeastern Kalkaska County fill in to some extent the gap between the western end of this ridge and the more massive moraine on the south side of Manistee River. Throughout its length this ridge is narrow, its average width being less than a mile; it is, however, prominent, rising on an average fully 50 feet and in places more than 100 feet above the bordering plains; in a considerable part of its course it stands above 1,300 feet and at a few points in Ogemaw County 1,400 feet or more above the sea. It is composed of loose-textured gravelly drift throughout, but it is on the whole more fertile than the plain on the south, having some fine loamy material mixed with its gravel and coarse material. A productive till plain lies south of this ridge in the northeast part of Roscommon County, but elsewhere the plain on the south is sandy.

From the bend of the West Branch morainic system at the line of Ogemaw and Oscoda counties a sharp ridge runs northwestward about 4 miles into Oscoda County. It leads toward ridges lying south and west of Luzerne in the western range of townships of Oscoda County, but is separated from them by a gap 6 or 7 miles wide, containing a sandy plain. Westward from western Oscoda County along the south side of Au Sable River to the vicinity of Grayling a somewhat intricate system of ridges and sand plains occupies a belt about 5 miles wide, about half of which is morainic; the ridges as well as the plains are sandy.

From the west side of Portage Lake near the west line of Crawford County a strong moraine 2 to 5 miles wide leads down the south side of Manistee River to the western part of Wexford County. It rises 100 to 400 feet above the river, its relief being much greater from northern Missaukee County westward than toward Portage Lake. Its altitude is generally a little above 1,200 feet, and in northern Missaukee County reaches 1,400 feet. The moraine is mainly of loose-textured gravelly drift but includes sufficient fine material along much of its course to make it suitable for agriculture, and it is occupied by several prosperous farming settlements. Tracts of clayey till lie on its inner slope, and narrow plains in places lie between it and Manistee River. A sandy plain, apparently outwash from the moraine, lies along most of its outer or southern border.

This moraine unites in western Wexford County with the Harrison-Lake City ridge, and the combined morainic system runs southward into Lake County. It lies along the western edge of the great Saginaw-Lake Michigan interlobate tract in eastern Lake and Newaygo counties, and its southern portion is not easily separated from that tract. Offshoots from it will be considered later.

RIDGES AT HEADWATERS OF AU SABLE AND MANISTEE RIVERS.

Two of the headwater tributaries of Au Sable River and the headwater portion of Manistee River lead southward from Otsego County into Crawford County through sags between prominent morainic ridges to the vicinity of Grayling, where the Au Sable turns eastward and the Manistee westward through a sandy plain. The ridges stand 100 to 200 feet above the intervening sags; they are highest at their northern ends, attaining an altitude of fully 1,400 feet; their southern ends are somewhat less than 1,300 feet. The ridges from the west branch of Au Sable River eastward appear to have been produced by ice moving westward from the Lake Huron basin, and those west of this stream seem to have been formed by an eastward movement in the Lake Michigan lobe. The central ridges were probably formed before those on either side, for the gravel plains or lines of glacial drainage lead toward the central ridges from those on the eastern and western borders of the system. (See Pl. VII.) The central ridges have at the surface bowldery clay a few feet deep, which was largely covered with maple forest, but which is now being rapidly cleared for farming. Wells indicate that sand sets in at slight depth, commonly 10 feet or less, and extends as far as the wells have been carried, or to 200 feet or more. The ridges on the eastern edge of the system are more sandy and less suitable for agriculture. The central ridges are on the whole less deeply indented by basins than the later ones. Portions of the eastern ridge are thickly set with basins 50 feet or more in depth. A few points on each ridge rise considerably above the general level, but much of their surfaces is gently undulating.

The drift of the valley-like depressions between the ridges is sandy and rather low in fertility, and consequently scarcely any of the lowland has been brought under cultivation. These plains have a southward slope and were apparently utilized by lines of glacial drainage flowing southward as far as Grayling. Thence the drainage appears to have been westward down the Manistee, for a well-defined channel leads from the Au Sable westward past Portage Lake to the

Manistee and is continued along the Manistee Valley. These features indicate that the border of the Michigan ice lobe had withdrawn to the north side of the west-flowing part of Manistee River in Kalkaska, Grand Traverse, and Wexford counties at the time these ridges were being formed. The Au Sable at that time appears to have been covered by the ice from the Huron basin at least as far up as western Oscoda County. These ridges seem to be somewhat younger than the system south of Au Sable River in southern Crawford County, for that system is apparently continued south of Manistee River. Their correlative is probably found in a fragmentary chain of knolls and ridges along the north side of the Manistee Valley.

To the east, north of the Au Sable River, lie extensive sandy plains which bear many basins and some knolls and short ridges. The best-defined ridge lies northwest of Mio; it is of crescent form, curves to the west, and is bordered by a till plain on the east and south. A small lobe of ice seems to have protruded eastward into the Au Sable Valley when this ridge was formed. Near the middle of the ridge, at a point about 6 miles north of Mio, a prominent point rises about 150 feet above the surrounding country, but elsewhere the relief is only 50 to 75 feet.

WEST BRANCH-GLADWIN GROUP OF MORAINES OF THE WESTERN LIMB OF THE SAGINAW LOBE.

By FRANK LEVERETT.

GENERAL FEATURES AND DISTRIBUTION.

The moraines formed by the Saginaw lobe in its recession from the Charlotte morainic system and prior to the readvance marked by the Port Huron morainic system are crowded closely together in the reentrant angles between the Saginaw and Lake Michigan lobes on the one hand and between the Saginaw and Huron-Erie lobes on the other, but are more widely spaced around the end of the Saginaw lobe. They are much more numerous south of the Grand River outlet than they are north of that outlet. The small moraines that branch from the northern portion of the western limb and bridge the reentrant between it and the Lake Michigan lobe are exceptionally complex and have already been treated (pp. 229-231). Here only the moraines along the Saginaw lobe north of the Grand River outlet are discussed; those at the end of the lobe and those on its eastern side are discussed later by Mr. Taylor (pp. 238-244). The western limb of the Saginaw lobe has strong development as far northeast as the bend of Au Sable River in Alcona County.

The portion of the bulky series of moraines between Au Sable River and Harrison, termed the West Branch morainic system, is 4 to 8 miles in width. (See PI. VII, in pocket.) It follows the line of Oscoda and Ogemaw counties westward from Au Sable River for about 15 miles, runs southward for an equal distance through central Ogemaw County, turns southwest-ward near West Branch, and continues for about 30 miles across southeastern Roscommon and northwestern Gladwin counties to Harrison in Clare County. There is some development of parallel ridges separated by narrow gravel plains or lines of glacial drainage in the portion between West Branch and Harrison, but northeast from West Branch there is only a single massive moraine.

In southern Clare County the West Branch morainic system separates into an outer strong moraine and an inner relatively weak one. The outer moraine, however, becomes separated a few miles farther southwest, in eastern Mecosta County, into two moraines, each of considerable strength. These two moraines bear southeastward across southwestern Isabella County into Montcalm County, where they turn southward across eastern Montcalm and northeastern Ionia counties to the Grand River valley. Just north of the river the outer of these moraines splits into three and the inner into two members.

The relatively weak inner moraine passes southward from southeastern Clare County through western Isabella County 2 to 5 miles from the inner edge of the stronger moraine. It crosses Chippewa River at the great bend a few miles west of Mount Pleasant, assumes considerable strength for a few miles, and bears southeastward into northwestern Gratiot County, its width being increased from less than 2 miles to about 4 miles. It then runs southward with diminishing strength through the western edge of Gratiot County to the Grand River outlet in the northwestern corner of Clinton County.

A small moraine, termed the Gladwin, lies east of the strong West Branch morainic system, with which it is connected only at its north end in southwestern Ogemaw County. It passes southwestward into northern Gladwin County, where it is interrupted for a few miles. It sets in again about 5 miles northeast of Gladwin and leads southwestward, passing just north of that town across western Gladwin County. It continues across southeastern Clare to central Isabella County just west of Mount Pleasant, crosses Chippewa River, and goes southeastward into Gratiot County. A ridge parallel to it on its inner border leads southeastward from just east of Mount Pleasant to St. Louis in Gratiot County. The two ridges unite near Ithaca and run southward to the Grand River outlet. From the outer ridge a spur leads southward from the northern part of Gratiot County to Elwell and may be continued a few miles farther south in a ridge that runs from about 3 miles southwest of Ithaca southward to the Grand River outlet. It thus appears that this moraine, which is a single ridge in the district north from Mount Pleasant, is separable into two and in places into three ridges between Mount Pleasant and the Grand River outlet. Beyond that outlet it finds continuation in the Flint moraine discussed by Mr. Taylor (pp. 241-243).

TOPOGRAPHY.

ALTITUDE.

The highest part of the West Branch morainic system is in southeastern Roscommon County, where it reaches an altitude of about 1,400 feet. A considerable part of it, from Harrison northeastward to Au Sable River, is above 1,200 feet, but its inner border falls to less than 1,000 feet. The interlobate spur between Au Sable River and the Lake Huron shore in Alcona County is largely above the 900-foot contour and in places above the 1,000-foot contour, and within 2 or 3 miles of the shore of Lake Huron it has points fully 800 feet above sea level, or more than 200 feet above lake level.

From Harrison southward the West Branch morainic system shows a steady decrease in each of its members clear to the Grand River outlet. The outer members are each a little higher than the next inner one throughout this entire distance. The outermost member near Ionia stands over 800 feet above sea level at the bluff of the Grand River outlet; the second is nearly 800 feet where it comes to the bluff; the third is but little above 700 feet at the bluff in northwestern Clinton County. The outer member shows the greatest range—about 600 feet—in altitude; the inner member, or rather the inner edge of the main system, descends little more than 300 feet from the border of the Au Sable Valley to the Grand River outlet.

The Gladwin moraine stands above 900 feet for a few miles in southwestern Ogemaw County and mainly between 800 and 900 feet from the Ogemaw County line to the Chippewa Valley at Mount Pleasant. A small tract in southeastern Clare County stands above 900 feet. From Mount Pleasant southward the 800-foot contour is reached only for a short distance in southeastern Isabella County. Elsewhere between Mount Pleasant and the Grand River outlet the altitude is between 700 and 800 feet.

RELIEF.

The relief of the moraine above the inner border district is greatest in Ogemaw and Roscommon counties, amounting in places to nearly 500 feet, and throughout much of the distance from Au Sable River to southern Clare County is more than 200 feet. Southward from Clare County, where the West Branch morainic system is separated into several members, the relief of each ridge is less than 100 feet except in northwestern Isabella and eastern Mecosta counties, where it is 200 feet or more.

Along the outer face of the West Branch morainic system throughout its entire length from the Au Sable Valley to the Grand River outlet, the relief is moderate, being generally less than 100 feet. In northern Clare, southeastern Roscommon, and western Ogemaw County, however, it in places reaches 200 feet.

The relief of the Gladwin Ridge is not more than 50 feet on either border except in Isabella and southeastern Clare counties, where it reaches nearly 100 feet on the inner border.

CHARACTER.

The closely crowded parallel ridges of the more massive portion of the West Branch morainic system become more and more distinctly separated in passing southward to the Grand River outlet. They are broken by a few gaps through which streams have passed from the outer border district into the inner border plain, the most conspicuous being that utilized by Chippewa River, which heads in the plains in southwestern Clare County and makes its way through each and all the members of the system to the inner border plain at Mount Pleasant. Pine River also cuts through several of the morainic ridges at places where they were weakly developed.

The great majority of the knolls through the entire length of the morainic system are relatively inconspicuous, but in a few places they rise to 100 feet or more, the most conspicuous being in the highest part in Roscommon and neighboring parts of Clare and Ogemaw counties. Ranges of hills in eastern Mecosta County also rise above 100 feet, but from the latitude of Mount Pleasant southward the moraines generally are composed of low knolls. A few knobs in the vicinity of Stanton are 100 feet more or less in height, but these seem to be outside the system under discussion and were apparently formed during the retreat of the ice from the Charlotte morainic system.

Basins are conspicuous along the entire massive morainic belt and along its constituent members toward the south. Many of them contain shallow tamarack swamps, but not a few hold small lakes.

The Gladwin Ridge has a swell and sag topography with fewer basins than characterize the main system. Its most hilly part is in Ogemaw County, where it also carries basins and some lakes.

STRUCTURE OF THE DRIFT.

The outer portion of the massive morainic tract from Au Sable River southwestward to Mecosta County, west of Mount Pleasant, contains a large percentage of gravel and sand, but much of its inner border carries a clayey till. In consequence much of the inner slope has been converted into farming land, and the outer is in large part a desolate waste in which brush is growing up to take the place of the pine forests that have been removed. In places the productive agricultural lands extend nearly to the outer border of the morainic system, for instance northeast and west of Harrison and in the northwest corner of Isabella County. The greater part of the outer slope of the morainic system, however, seems better suited for forest than for agriculture.

The greater portion of the morainic system from Clare County southward to the Grand River outlet has a soil suitable for productive farming and is largely under cultivation; the moraines are better farming land than the depressions that separate them, the latter being sandy

and swampy lines of glacial drainage. In Gratiot, Montcalm, and central Isabella counties the moraines are separated by broader strips of fertile till plain, which he on the inner slopes of the moraines and not, like the drainage channels, on the outer slopes. The constant repetition of the series, drainage channel, moraine, and till plain, brings out clearly the glacial and fluvioglacial relations and conditions.

The Gladwin moraine has sufficient till along its entire course to render it profitable for agriculture, but in the gaps in northeastern Gladwin and southeastern Ogemaw counties and at Au Sable River in northwestern Iosco County its soil is relatively inferior, much of it being a light sand. There is also a sandy tract all along the outer border of this moraine from Au Sable River to the Chippewa, very little of which has been brought under cultivation.

Bowlders and cobblestones are conspicuous on the surface and in the upper part of the drift on the outer face of the main morainic system from the Au Sable Valley to within a few miles of the Grand River outlet but are relatively inconspicuous in southeastern Montcalm and northeastern Ionia counties. On the inner slope bowlders are common.

On the Gladwin moraine bowlders are conspicuous in parts of Ogemaw and Iosco counties, but as a rule they are not much more numerous than on the bordering plain and are less abundant than on the West Branch morainic system.

As the principal settlements are along the inner or eastern face of the large morainic belt in Ogemaw and Claire counties, and as no extensive settlements have been made in Roscommon and Gladwin counties, information is rather fragmentary concerning the deeper parts of the drift. In the interlobate spur in Alcona County the wells are shallow, but some deep ones on its south border at Killmaster show that the thickness of the drift is great. Deep wells at Mount Pleasant, Gladwin, Alma, St. Louis, and Ithaca, along or near the line of the small moraine east of the main system, also show a great thickness of drift in this low-lying district. There is no reason for suspecting the rock surface to have a greater altitude beneath the main morainic system than in this district, and it is probable that the higher ridges bear as much as 700 feet of drift. The following table sets forth the altitude of the bedrock, so far as known, along the inner edge of the morainic system:

Altitude of bedrock surface along and east of the West Branch morainic system.

Location.	Altitude of well mouth.	Thickness of drift.	Altitude of bedrock.	Remarks.
	Feet.	*Feet.*	*Feet.*	
Rose City, heading mill	935	233	702	Well is 241 feet.
West Branch, livery	953	180	773?	Bits of coal near bottom. Rock doubtful.
Edwards Lake, sec. 28, T. 21 N., R. 1 E	850	203	647	Well is 238 feet.
Chapman Lake, sec. 32, T. 21 N., R. 1 E	840	185	655	Well is 403 feet.
Gladwin waterworks	765	160	605	Well is 465 feet.
Estey, sec. 25, T. 17 N., R. 2 E	700	140	560	Well is 300 feet.
Clare, coal boring	834	275+	559—	Stops in quicksand.
Five Lakes, sec. 16, T. 17 N., R. 4 W	900	280+	620—	No rock struck.
Mount Pleasant, bromine well	770	435	335	Well is 1,585 feet.
St. Louis, Harrington well	753	335	418	Well is 600 feet.
St. Louis, Andrews well	753	203	550?	Rock may have been struck (shale).
Alma Sanitarium	756	500	256	Well is 2,863 feet.
Ithaca	751	330	421	Well is 613 feet.
Ashley	670	50	620	Well is 275 feet.
Ashley, 1 mile north of	675	190+	485—	No rock struck.

The well sections given below are among the deepest obtainable. They are taken in order from northeast to southwest, beginning in northeastern Ogemaw County.

Isaac Lupton's well, 11/2 miles north of Lupton, at an altitude about 1,050 feet, is 125 feet in depth and penetrated only 16 feet of till, the remainder of the section being sand.

In and around Rose City, which stands at the eastern base of the large moraine, many strong flowing wells appear to obtain water from gravel beds interbedded with till at different horizons.[1]

At Campbells Corners, at an altitude of about 1,080 feet, a well made by James Campbell penetrated 10 feet of till and 120 feet of sand to its bottom.

At West Branch wells sunk by C. J. Blakeley and C. J. Phelps to depths of 185 and 152 feet, respectively, penetrated a large amount of till and near the bottom entered sand containing bits of coal. The water flows with a strong head and frequently brings up coal. It is doubtful, however, if the bottom of the drift was reached.

[1]Water-Supply Paper U. S. Geol. Survey No. 183, 1907, p. 291.

A well at Georges Lake, in sec. 18, T. 21 N., R. 2 E., penetrated 19 feet of till, 91 feet of sand and gravel, and 60 feet of a gray clay called "soapstone," beneath which lay gravelly clay and then sand to a depth of 214 feet. The "soapstone" may be only a hard till.

A well at Edwards Lake, in sec. 28, T. 21 N., R. 1 E., penetrated sandy clay 48 feet, sand 112 feet, red clay 10 feet, and red sand 33 feet, beneath which sandstone was struck at a depth of 203 feet. The well was continued in rock to a depth of 238 feet.

At Chapman Lake, in sec. 32, T. 21 N., R. 1 E., a well penetrated clay 30 feet, gravel and sand 70 feet, sandy clay 50 feet, sand 20 feet, and gravelly clay 15 feet, below which alternations of sandstone and other rock formations extended from 180 to 403 feet.

Jacob Schwartz, 1 mile north of McClure, Gladwin County, made several flowing wells just north of the small ridge which runs past Gladwin; they are about 100 feet in depth and are largely through a clayey till. Other borings in and around Gladwin pass through considerable till with thin beds of gravel and sand from which they obtain flowing wells; some, however, are carried into the rock.[1]

OUTER BORDER.

From Mecosta County northward the district outside West Branch morainic system is largely occupied by sandy outwash aprons, which drained southwestward through Muskegon and Little Muskegon rivers. The outwash has an altitude of about 1,200 feet in southern Oscoda County and in much of Roscommon County, but from southwestern Roscommon County it slopes rapidly southwestward down the Muskegon Valley. In Mecosta County the glacial drainage led southward and westward through the Little Muskegon Valley.

In Montcalm County the border is very complex. Its limits are less definite than in districts to the north, and

there is some uncertainty as to where they should be drawn. The best-defined moraine runs past Edmore and just east of McBride and Stanton, and then swings southwestward toward Amsden. But outside of this there is a district in which sharp knobs and clusters of hills are surrounded by nearly plane tracts. West of these knobs and the surrounding till there are tracts of nearly plane sandy gravel, which may perhaps be an outwash from the ice border at the time the sharp knolls were forming. If these knolls are included in the West Branch morainic system the border runs nearly directly south from southeastern Mecosta County across Montcalm County and passes just west of the city of Stanton. Mount Dodge, the highest of the knobs, situated 11/2 miles northwest of Stanton, has an altitude of about 190 feet above Stanton station, or 1,082 feet above sea level. From it lower knolls extend a short distance southwest and west, and a sharp range of hills leads northward about to Westville, a distance of 4 miles. These are all gravelly kames, and the district immediately west is a plain of sandy gravel, probably an outwash.

A small esker at the north end of this range of hills leads northwestward for 3 miles from near the Pere Marquette Railroad about a mile south of McBride across secs. 17 and 7, Day Township, and sec. 1, Douglas Township. The esker is 10 to 20 feet in height, but has several small gaps. It lies in an esker trough, which is rather obscure at the southeast end, but is well defined from sec. 7, Day Township, northwestward beyond the end of the esker to the Flat River valley in sec. 28, Belvidere Township. Its width is one-half to three-fourths of a mile, and its surface is 10 to 20 feet or more below the bordering plain. Its extension beyond the esker is through a tract of sandy till.

Northern Belvidere Township, Montcalm County, and northeast Cato Township are dotted with sharp knolls 50 to 75 feet high, but much of their surface is very gently undulating. The knolls are gravelly, but the undulating tracts consist of a loose-textured, sandy to gravelly till that seems to merge at the northwest into the great outwash plain along the Little Muskegon River. This district adjoins a strong moraine in Millbrook Township, Mecosta County, which also fronts on the outwash apron. The features strongly support the inclusion of this knolly undulating tract with the morainic system under discussion, though as already indicated a line of stronger morainic features leads southeastward from Millbrook Township toward Edmore.

[1]Water-Supply Paper U. S. Geol. Survey No. 183, 1907, p. 114.

The district southwest from Stanton as far as Greenville and thence southward along the east side of Flat River into Ionia County is characterized by a large number of basins, some of which cover 1 to 2 square miles or more. Knolls, however, are low and scattered, and the greater part of the surf ace is nearly plane. The drift varies greatly in texture, some of it being loose and gravelly and some being a typical till. Gravel and sand, however, predominate greatly over till for 4 or 5 miles east of Flat River, from the latitude of Stanton southward about to Greenville. The till is best exhibited in a belt 3 to 4 miles wide leading from Stanton southwest-ward through central Sidney Township and western Fairplain Township. Immediately east of this belt of till lies the morainic belt which may prove to be the outer member of the system under discussion. At present, however, it seems more probable that the ice at the beginning of the development of this morainic system extended across Montcalm County about to the Flat River valley. The basin tract under discussion continues southward across northwestern Ionia County, crosses the Grand River outlet near Saranac, and continues about to Morrison Lake, where it turns southeastward toward Lake Odessa, keeping just east of the eastern member of the Charlotte morainic system. Till is more conspicuous on the plane tract around the basins and is more clayey in Ionia County than it is in Montcalm County.

GLACIAL DRAINAGE.

A strong line of glacial drainage seems to have led along the line of Montcalm and Ionia counties into the Flat River valley near Belding. With the recession of the ice this drainage was extended eastward to northwestern Ronald Township, Ionia County, just east of Shiloh. Its channel, which was 3 to 5 miles wide, including a few small knolls around which the glacial drainage apparently passed, received a feeder from the north along Dickinson Creek from near Amsden. On either side, in Fairplain Township, Montcalm County, and in Orleans Township, Ionia County, lie the tracts of gently undulating till containing the large basins that are discussed above.

The Grand River outlet, whose features have been studied more particularly by Mr. Taylor (pp. 255, 360), probably served as a strong line of glacial drainage throughout the development of this morainic system.

Between the outer and second of the constituent ridges of the system in southwestern Isabella County a gravel plain sets in and leads southeastward into Montcalm County nearly to Vestaburg. The river passes eastward through the moraine on which Vestaburg stands, but the glacial drainage probably continued southward through a series of narrow channels in western Ferris Township to a well-defined line of border drainage in secs. 19 and 30, Ferris Township, which continues southward along the west edge of the moraine to the Grand River outlet in Ionia County. Its general width is about a mile, though in places it narrows to less than one-half mile. The descent of this border drainage is about 200 feet in 50 miles from its head in southwestern Isabella County to the Grand River outlet (from 900 to 700 feet above sea level). The material along the whole line of the channel, so far as seen in exposures, is fine sandy gravel, scarcely coarse enough for road ballast.

The line of glacial drainage between the second and third moraines is continuous from southern Clare County to the Grand River outlet, a distance of about 70 miles.

It heads near Hatton and passes southwestward, leaving Farwell at its east border, and enters the Chippewa Valley drainage in northwestern Gilmore Township, Isabella County. It then passes south to the bend of the Chippewa west of Mount Pleasant, from which point the water may have led westward into the valley of Pine River through a break in the second moraine and thence to the Grand River outlet along the line just outlined. Or, more probably, its greater part may have passed southward by Dushville through a swampy depression which drains into Pine River in northwestern Gratiot County, followed Pine River past Riverdale to Sumner, and continued southward to the Grand River outlet along the line of Gratiot and Montcalm counties. At its source this second line had an altitude of about 1,000 feet and descended 300 feet to reach the Grand River outlet. Its width ranges from 1 mile or less up to 5 miles. In much of its course across Isabella County it is spread out in a plain 2 to 5 miles wide, composed largely of fine sandy gravel; as in the glacial drainage line to the west.

The glacial drainage connected with the Gladwin moraine probably passed southwestward through narrow channels between morainic ridges in western Gladwin and southeastern Clare counties, though the details have not been worked out. From the village of Clare a well-defined border drainage channel, filled with a sandy outwash, leads southwestward to the Chippewa Valley, southward from which a depression on the outer border of the moraine leads into Gratiot County. So far as noted this depression is nearly free from sand or gravel deposits, but it seems likely, nevertheless, to have been followed by the glacial waters. In Gratiot County a low plain lies west of this weak morainic belt but appears to bear little outwash. The writer has not made a detailed study along the morainic belt, but there appears to have been no obstruction to the southward passage of water along the outer edge of the ice into the Grand River outlet through western Gratiot County.

MORAINES OF THE EASTERN LIMB OF THE SAGINAW LOBE.

By FRANK B. TAYLOR.

DISTRIBUTION.

GENERAL FEATURES.

The moraines of the southern and eastern borders of the Saginaw lobe lie between the Grand River channel and the west line of Lapeer County. Grand River channel, which will be fully described later (pp. 255-259, 360), extends westward from Gratiot County to Lake Michigan. It is occupied from southeastern Gratiot County by Maple River, which flows westward and south-westward as a sluggish stream wandering on a swampy floor of a mile-wide valley. It is entered from the south by Grand River at Lyons, about 40 miles east of Grand Rapids, and it takes its name from that stream throughout its length of about 75 miles. It cuts directly across the West Branch-Gladwin group of moraines, on a line a little north of the central axis of the Saginaw Valley produced southwestward.

That part of the West Branch-Gladwin group of moraines which lies north of the Grand River channel (described by Mr. Leverett, pp. 232-238) generally shows much complexity in the northern part of the State, although clearly separate from other moraines which preceded and followed it.

North of West Branch the deposits have the appearance of a single massive moraine of irregular form, but in their extension southward to the vicinity of Harrison and Gladwin they change remarkably to a complex of short morainic ridges, overlaps, spurs, loops, and irregular knolly patches. Farther south they divide and spread more and more widely into separate individuals with roughly parallel courses. At the north side of the Grand River channel the deposits have a width of nearly 40 miles, and 5 to 10 miles farther south their slender ridges are more perfectly set apart as individuals, spreading over a width of more than 50 miles. This change in form from an essentially single, massive individual to many slender, distinct individuals is not equaled in any other locality now known.

The distribution of the moraines in the district is dependent in part at least on the relation of the Saginaw ice lobe to the topography. As the ice advanced out of the deeper basin of Lake Huron, it deployed on all sides upon a relatively smooth plain that sloped very gently upward in all directions. The upward slope was a little less toward the south than toward the west and was still less toward the southwest. The ice adapted itself to the form of the wide, shallow basin with minute fidelity. Its front took on ail unusually symmetrical form, now revealed by the configuration of the terminal moraines. A straight line drawn from the center of Saginaw Bay (about 20 miles northeast of Bay City) southwestward to the village of Hastings in Barry County divides the moraines into almost perfectly symmetrical halves. The symmetry is perhaps a little more perfect if the division is along a line 5 to 10 miles southeast of and parallel with the real axis. The best developed area is in Clinton, Ionia, Shiawassee, northern Eaton, and southern Saginaw counties and extends almost as perfectly into Genesee County. In this area the moraines are remarkably parallel for about 85 miles. In the typical area they are so remarkable for the simplicity of their configuration and grouping that it seems important to describe them somewhat fully.

Where the morainic ridges are most typical and most widely deployed they are all of about the same strength and are almost equally spaced, indicating apparently that they are all fully developed single individuals of their class, and that no one of them represents a combination of two or more such individuals. In Clare and Montcalm counties some of the more massive ridges come within 6 or 8 miles of the Grand River channel before they divide into their ultimate units, but all the ridges that cross the channel appear to be single individuals.

These slender moraines number a dozen or more, each named for some city or village through or near which it passes. Their names, beginning with the oldest, are as follows, the last three being water-laid and fainter than the rest: (1) Lansing, (2) Grand Ledge, (3) Ionia, (4) Portland, (5) Lyons, (6) Fowler, (7) St. Johns, (8) Flint, (9) Owosso, (10) Henderson, (11) West Haven, and (12) Chesaning; still another very faint member lies north of the Chesaning. Possible equivalents of the Flint moraine are the Maple Rapids and Eureka ridges.

Where deployed in open order these slender moraines possess characteristics very different from those of most of the other moraines of Michigan. They are predominantly clayey, generally yellowish gray or brownish gray on weathered surfaces, and they contain comparatively few bowlders and small quantities of pebbles or water-assorted materials. Their width varies from one-eighth mile to 2 miles, averaging about 1 mile, and rarely exceeding 11/2 miles. Their relief above the adjacent flat till plains is generally low and as a rule their surfaces are comparatively smooth. The highest knoll in any of them, where they stand apart as separate individuals, does not exceed 60 feet above the plain and their average crest height does not exceed 20 feet. In some places they fade out to a broad, low swell scarcely perceptible to the eye and in other places to scattered low knolls scarcely 5 feet in height.

Where these moraines overlap—the later ones overriding the earlier—as they do eastward from Lansing, their characteristics are entirely different. They become broken and irregular— more massive, wider, and higher in places, more steep-sided, and more rugged. Their normally even trend is destroyed and they include many lakes and swamps in reentrants and transverse and irregular depressions. In these areas they resemble more nearly the massive rugged moraines of other parts of Michigan, except that they are narrower and smaller.

LANSING MORAINE.

The relatively massive West Branch morainic system crosses the north line of Ionia County and runs southward. About 4 miles from the line it divides into three slender moraines which diverge toward the south and southwest. The most westerly of the three reaches the Grand River channel about 3 miles west of Ionia, at which place it is about 11/2 miles wide. This is the northern limb of the Lansing moraine. Beyond the channel for about 10 miles south no certain continuation exists, but 3 or 4 miles northwest of Lake Odessa scattered morainic knolls appear, and from the east bank of the lake a well-defined but very slender moraine, here called the Lansing, extends eastward through northern Eaton County to the southern part of Lansing, a distance of over 25 miles, passing through the villages of Lake Odessa, Sunfield, and Mulliken. Where it passes about 2 miles south of Grand Ledge this moraine is extremely narrow though sharply defined. For 5 or 6 miles in T. 4 N., Rs. 3 and 4 W., it is hardly one-eighth mile wide, but it is perfectly continuous, and although it is only 10 to 20 feet high, is conspicuous above the flat till plains on either side. Elsewhere its usual width is from three-fourths of a mile to a mile.

At Lansing the moraine is cut through by Grand River and by Sycamore Creek, and becomes otherwise broken and irregular where it passes over the north end of the Mason esker. Eastward it extends in broken, irregular form at least as far as Okemos, but beyond this its exact course is uncertain. It may possibly run eastward along Cedar River, passing in very faint form just north of Williams ton. A more probable course, however, is northeastward from Okemos past Pine Lake and Alverson, where it either turns abruptly southeast or is combined with the next later moraine. The region of marked overlapping extending eastward from Okemos will be described later (pp. 244-245).

GRAND LEDGE MORAINE.

The second slender moraine of the series, known as the Grand Ledge moraine, comes down to the north bank of the Grand River channel about 2 miles west of Ionia, between the Pere Marquette Railroad and Bellamy Creek, and is there very narrow, hardly more than a quarter of a mile wide. On the south side of the channel, beyond a break of about 2 miles, it reappears, but for 3 miles it is very slender, being scarcely more than one-eighth mile wide. Toward Orange it grows stronger, its width being about three-fourths of a mile. For about 8 miles from the channel it runs a little east of south, but a mile south of West Sebewa it turns east-southeast and passes just north of Cornell and Danby, close along the south side of Grand River as far as Grand Ledge, though it is much broken for 4 miles west of this place. East of West Sebewa it is about a mile wide and 15 to 30 feet high. The main part crosses to the north of the river at Grand Ledge and is higher and stronger for 7 or 8 miles east. From Grand Ledge it runs directly east to a point about 2 miles north of Lansing, where it turns southeast. Northeast of Lansing it is more than a mile wide and unusually high. This section of the moraine runs about 4 miles southeast to the Michigan State Agricultural College, where it abruptly turns nearly 90° to the northeast, forming a small, sharply pointed lobe, with the college about one-half mile west of the apex. At the apex the moraine is broken by glacial drainage which issued toward the south. Two miles northeast of the college the moraine is again strongly developed and continues so to the north side of Pine Lake. North from the apex and partly inclosed by the strong limbs of this small lobe lies the great Chandler Marsh, probably a shallow lake formerly and now the largest marsh in this part of the State.

IONIA MORAINE.

The third or Ionia moraine comes down from the north and curves sharply to the southwest just before entering Ionia. In the northern part of the city it is about 2 miles wide and 20 to 25 feet high. South of the channel it curves southeast a little more directly than the Grand Ledge moraine and keeps in close parallelism with it

nearly to Lansing. It crosses Grand River about 2 miles south of Portland and follows its north side to Eagle. Beyond this it becomes broken and irregular, like the others, but continues almost directly east to the southwest corner of Genesee County, passing south of Wacousta and Dewitt and through Gunnisonville and Bath. Farther east it passes just north of Shaftsbury and East Cohoctah, where it appears to be overridden by a later moraine. From Ionia to Bath it is rather more slender than the earlier ridges, but gains in strength toward the east.

PORTLAND MORAINE.

The next moraine of the deployed group, known as the Portland moraine, comes down to the north bank of the Grand River channel about 2 miles west of Muir with a width of about a mile. Directly opposite on the south side and about 11/2 miles southwest of Lyons it reappears and runs southeast, crossing Grand River east of Collins, and forming the high bluff on the north side of Lookingglass River at Portland. Beyond this it curves gradually toward the east, keeping close to the north side of Lookingglass River and crossing to the south side just east of Dewitt, about 7 miles north of Lansing. Thence it runs east through the northern part of T. 5N., Rs. 1 W., 1 E., and 2 E. (Bath, Woodhull, and Perry townships), passing the hamlets of Perry and Grass River, and trending a little south of east through the central part of T. 5 N., R. 3 E. (Antrim Township) and across the southwest corner of Genesee County, where it appears to override the Ionia moraine. This moraine is somewhat stronger than the Ionia moraine.

LYONS MORAINE.

The next moraine, the Lyons, comes down to the north bank of the Grand River channel about a mile northeast of Muir and begins again on the south side a mile east of Lyons. From this point it runs southeast past Westphalia and Riley post offices and thence eastward to Laingsburg. Near Westphalia and Riley it is very weak, scarcely traceable, but is stronger farther east. Three or 4 miles east of Laingsburg it crosses Lookingglass River and runs east-southeast to the southeast corner of Shiawassee County, where it appears to override the next earlier moraine. It runs on east in broken form, passing Argentine and a little north of Fenton, turns northeast through the extreme northwest corner of Oakland County, and passes a little south of Atlas into northeast Lapeer County. This moraine seems slightly weaker than the Portland moraine.

FOWLER MORAINE.

The Fowler, one of the finest moraines of the group, comes from the north to the Grand River channel at Matherton about 12 miles northeast of Ionia. South of the channel it runs southeast, passing a little west of Fowler. About 4 miles southeast of Fowler the moraine crosses to the south side of Stony Creek and loses its strength, continuing for 5 or 6 miles as a faint and broken feature. Beyond this, however, it is stronger, and though rather narrow continues as a sharply defined ridge through T. 6 N., Rs. 1 W., 1 E., and 2 E. (Victor, Sciota, and Bennington townships). Its height is in places 40 to 50 feet. Two miles east of Hartwellsville it turns southeast, crosses Shiawassee River, and follows its north side to Linden, whence it runs northeast near Grand Blanc and east of Davison, turns more nearly north, and enters Lapeer County about 2 miles northwest of Elba. Through Shiawassee and Genesee counties this moraine is sharply defined. Between Byron and Grand Blanc it passes along the north side of a jumbled, overlapped area, but is sharply separated from it by a well-defined valley, which contains Shiawassee River and a number of lakes.

ST. JOHNS MORAINE.

The identity of the St. Johns moraine north of the Grand River channel is uncertain. At St. Johns it is a narrow sharp ridge rising 30 to 40 feet above the plain to the north and about 20 feet above the plain to the south. From St. Johns it curves gradually northwest, diminishing in strength for about 5 miles, when it ceases to be a ridge and for a mile or two is represented by scattered knolls that finally die out. Its course indicates that it should reach the Grand River channel 2 or 3 miles below Maple Rapids. But no distinct moraine comes to the channel in that vicinity, nor is one recognizable south of the channel for 6 or 7 miles.

Eastward from St. Johns to within a mile of Shepardsville the moraine is rather faint and broken, with low parallel ridges north of a rather weak main ridge. Farther east it is much stronger, with an average width of a mile, and runs a little south of east across Shiawassee County, crossing Shiawassee River at Newburg, and continuing in the same general direction to a point 3 miles southeast of Gaines in Genesee County, where it turns sharply northeast, passing a mile south of Rankin. To Thread River south of Flint the front ridge is fairly strong. In T. 6 N., Rs. 5 and 6 E. (Gaines and Mundy townships), it is accompanied by later, weaker, fragmentary, approximately parallel ridges that lie 1 to 4 miles north of it. From Thread River to near Richfield it is very faint, being represented only by low, scattered knolls. This weakness is probably due to a narrow lake which lay along the front of the ice southwest from Richfield at this stage of retreat. Crossing Flint River from near Richfield the moraine grows much stronger and higher toward the northeast, and then bends abruptly eastward and passes into Lapeer County.

FLINT MORAINE, BOWLDERY BELT, AND OTISVILLE MORAINE.

The village of Maple Rapids is barely within the head of the Grand River channel. One mile east of Perrinton, which is 6 miles north of Maple Rapids, a sharply defined, narrow till ridge, known as the Perrinton Ridge, runs north and south. Another stronger moraine runs south from Ithaca along the line between T. 10 N., Rs. 2 and 3 W. (Newark and North Star townships) and then turns southwest through central T. 9 N., R. 3 W. (Fulton Township) to the Grand River channel north of Maple

Rapids. (See fig. 1, p. 258.) The first ridge, which appears to have run southward from near Perrinton across the channel 1 or 2 miles northeast of Maple Rapids, is clearly out of harmony with the second, which appears to project as a sharp tongue down the channel. It looks as if the first moraine was built before the channel was in existence, and that the second one came later, after the channel had been made, and that the ice was guided by the channel in the formation of the sharp tongue. The topography on the south side of the channel seems to support this view, for the moraines there are broken and irregular, though two main ridges corresponding to the two on the north side are easily made out. The first, which may be called the Flint moraine, seems certainly to be a continuation of the Perrinton Ridge, which would run into it if produced southward. It begins abruptly on the south side of Maple River as a high, steep bluff rising close above the stream. For 2 or 3 miles to the southeast it runs as a double ridge with a small, narrow clay flat between, the eastern ridge being the smaller of the two. From this on for 9 or 10 miles east to Duplain it is represented only by scattered knolls in a flat clay plain which is sometimes swampy.

Beyond Duplain it reappears as a strong ridge and 2 miles east of the village makes a sharp loop to the north around a flat hollow about 2 miles in diameter. This hollow is almost surrounded by the moraine, remaining open only to the southwest. On account of this irregularity the moraine has unusual breadth north of Ovid. East of Ovid it is cut through by an esker trough which enters from the northeast, turns west, and runs nearly parallel with the moraine. At its mouth it contains an esker nearly a mile long, which also parallels the moraine; a very exceptional course for an esker.

Some of the irregularities in this moraine from Maple Rapids to Ovid may be due to a readvance of the ice, but others appear to be due directly or indirectly to the presence and influence of the great outlet river which flowed close along the front of the ice at that time.

The moraine grows unusually wide again south and west of Owosso and is cut through by a wide, low trough. Shiawassee River cuts through it at Vernon and a smaller stream northwest of Duffield. With these exceptions it runs with even strength from Ovid to Flint. It is prominent and controls much of the drainage. From Ovid to a point north of Durand it runs a little south of east, but between Vernon and Duffield it curves gradually around through east to east-northeast and keeps this direction to Flint. From Corunna east it is half a mile to a mile wide and rises 30 to 50 feet above the channel floor south of it. Its trend on entering the western part of Flint is east-northeast.

Flint seems to be situated at the former apex of a blunt ice lobe, for a probable continuation of the moraine runs north from the north side of the river nearly to Mount Morris and there turns northeast and passes near Thetford into Tuscola County. Flint River here follows the last position of the Imlay outlet channel. It enters Flint from the northeast and turns west-northwest, cutting a gap about a mile wide through the moraine. The moraine on the north bank is weaker for 2 or 3 miles than the one west of Flint and seems to stand somewhat out of line with it, even if the apex of a lobe was at Flint. Still, it is almost certainly the continuation of the Flint moraine. The lack of alignment suggests that the part north of the river may represent only the inner part of the Flint moraine.

Other facts give some support to this supposition. A well-defined bowlder belt which runs northeast from Flint to the river south of Rogersville rests on the flat till plain, but may represent the continuation of the outer part of the Flint moraine, for the morainic features farther northeast seem to require the continuation of the ice front across this bowldery interval.

Another strong morainic area lies just south of the river on the township line east of Genesee and still another smaller one on the north side a mile northeast of Genesee; perhaps both belong to the Flint moraine, but their relations are not entirely clear. In the northwestern part of Richfield north of the river, however, morainic knolls appear and increase rapidly in strength and continuity toward Otisville, forming what may be termed the Otisville moraine. They grow still stronger farther northeast on the north side of the railroad to and beyond the corner of the county. The morainic features are very irregular, but the moraine has outwash at several points on its east side and is sharply separated from the next later moraine by a strong line of ice-border drainage which follows Butternut Creek toward the southwest. In passing northeastward out of Genesee County this moraine bends a little to the east and crosses the extreme northwest corner of Lapeer County. Its front passes just north of Otter Lake, north of which for a mile or more it is very high, reaching an altitude of over 1,000 feet above sea level.

The bowlder belt northeast from Flint appears to follow the normal course of the Flint moraine produced, and the Otisville moraine continues in the same line. If the moraine running north from Flint is the continuation of the Flint moraine, the bowlder belt and the Otisville moraine appear to be left as detached fragments out of harmony with the earlier and later members of the group and without visible representation toward the west. The Otisville moraine is roughened, as if by overriding some earlier moraine or other feature of considerable relief. Though the preponderance of evidence seems to favor the ridge going north to Mount Morris as the continuation of the Flint moraine, the alternative course past Otisville remains open.

OWOSSO MORAINE.

The Owosso moraine passes Ithaca and runs south a few miles and thence southwest to the bank of the Grand River channel at Maple Rapids. (See fig. 1, p. 258.) It is a strong, even, continuous ridge. The first ridge (in double form) east of Maple Rapids appears to be part of the Flint moraine. But just east of this, in the

northeast part of sec. 2, T. 8 N., R. 3 W. (Essex Township), another moraine, extremely broken and bearing a number of kames and other irregularities, sets in and runs east past Union Home and Eureka. The north face of this moraine is a high, steep bluff, evidently cut away since the moraine was made. Lake beaches along its base may account for part of the cutting but not for the most of it. (See p. 258.)

On the north side of the river the Owosso moraine bends southwestward into the head of the channel and near Maple Rapids virtually forms its north bank. On the south side the trend of the moraine is also westward to the head of the channel. (See fig. 1.) Taken together these two moraines seem to mark the sides of a sharp ice tongue which projected westward to the head of the channel and down it through and beyond the Flint moraine. The cause of this relation will be discussed in connection with drainage (pp. 257-259).

From near the township line 2 miles southeast of Eureka eastward to about 2 miles east of Elsie there was either no morainic deposition or else the moraine was afterward washed away. Beyond this gap the moraine runs southeast as a more continuous and even ridge, passing just north of the cities of Owosso and Corunna and 4 or 5 miles north of Durand. Farther east, toward Flint River, it turns a little north of east and grows much fainter.

If the Flint moraine finds its continuation in the Otisville moraine, then it would seem almost certain that the moraine running north from Flint to Mount Morris is a continuation of the Owosso moraine. Otherwise the Owosso is probably continued in one of the ridges passing just north of Mount Morris and south of Millington.

HENDERSON MORAINE.

The confusion among the slender moraines about the head of the Grand River channel makes it difficult to identify the members. A mile or two northeast of Maple Rapids the channel begins to open out into the basin of Saginaw Bay. The divide between Maple River, which flows west through the Grand River channel, and a branch of Bad River, which flows northeast to Saginaw Bay, is about 11/2 miles northeast of Bannister and about 14 miles east of Maple Rapids. West of this divide much of the lake floor approaching the head of the Grand River channel is thickly strewn with bowlders. In a few places fairly distinct belts occur, one of which runs southeast on the divide east of Bannister and is continued in a distinct morainic ridge, known as the Henderson moraine, which begins about a mile south of Chapin and runs southeast, passing about a mile south of Henderson. Southwest of Chapin three smaller ridges lie between the Henderson and Owosso moraines. From Henderson the Henderson moraine runs eastward to the west bank of Flint River, about 2 miles northwest of Flushing, but it is very faint in this interval and has not been traced continuously. East of the river at Flushing a faint moraine runs south, apparently marking a short, sharp tongue projecting up the river. This moraine is probably represented by one or both of the narrow ridges which pass just north of Mount Morris; it is quite distinct through T. 9 N., R. 7 E. (Thetford Township), and passes 11/2 miles south of Millington.

WEST HAVEN MORAINE.

A bowldery belt on the old lake bottom about a mile north of Chapin is probably to be identified with another moraine, which, however, is perhaps not land-laid in this part of the Saginaw Valley. It is not entirely clear whether this moraine, which has been called the West Haven moraine, is a separate individual passing a little south of Oakley, a mile or so northeast of West Haven and a little south of New Lathrop, or whether it belongs to the moraine next mentioned below. Faint indications of such an individual exist 2 miles northeast of West Haven, and regularity of space interval seems to call for it, but it was not identified further.

CHESANING MORAINE.

A very bowldery belt south and west of Laytons Corners marks the course of another moraine, known as the Chesaning. It extends in all about 8 miles or to Shiawassee River south of Chesaning. This belt is slightly below former lake level (10 to 25 feet) and is in the surf-wasted zone of the Arkona beaches, which are the strongest in this part of the Saginaw Basin. Wave work has removed the fine material and left the ground very stony but has not destroyed the morainic knolls, which though low are well defined. The moraine was water-laid, but the water was shallow. This fragment stands alone and was not traced in either direction; it may, however, be continued east of Flint River in the ridge upon which the Arkona beaches rest between Clio and Millington, but this correlation is not certain.

MORAINE NORTH OF CHESANING.

Another faint bowldery tract 2 miles northwest of Chesaning appears by its altitude and general relations to belong to another later moraine, which, however, was not certainly identified elsewhere.

OVERLAPPING OF THE EARLIER MORAINES OF THE DEPLOYED GROUP.

The morainic features in the tier of townships east of Lansing are extremely irregular, the later moraines appearing successively to override the earlier ones. The Lansing, Grand Ledge, and Ionia moraines appear to be involved in the overlapping as far as northeastern Livingston County.

If the Lansing moraine turns southeast from Alverson (see p. 239), it seems probable that it includes the morainic fragments at least as far east as northern Livingston County and that in this interval it overrides earlier morainic deposits. On the the other hand, if the Lansing moraine is overridden east of Alverson by a later moraine, then the fragments may belong to this next later (Grand Ledge) moraine. The morainic deposits are so cut up by transverse troughs and their

trends vary so much that it is scarcely possible to identify individuals continuously. But to whichever moraine the fragments in northern Livingston County belong, they appear to be overridden there and eastward by a still later moraine. In fact, though the morainic jumble into which the first three moraines of the deployed group disappear may be partly due to irregularities in the rock surface beneath the drift, it seems to be due chiefly to marginal overriding or overlapping.

The Grand Ledge moraine enters the broken belt north of Lansing; the Ionia moraine enters farther to the east, in the southwest corner of Shiawassee County; the Portland moraine enters near the southwest corner of Genesee County. From here the broken belt extends eastward into northwestern Oakland County, and, although narrower than at points farther west, it seems to include the Ionia and Portland moraines.

On entering Lapeer County the Portland moraine seems to stand out clearly as the front moraine of the deployed group, although on the meridian of Lansing it is the fourth. This relation, however, is not altogether certain, for it is possible that one or more of the earlier moraines of the group not yet identified emerges from under the later moraines and runs along the face of the higher ground to the south.

In northwestern Livingston County, 5 miles north of Howell, a crescent-shaped morainic loop, the identity and relations of which have not been certainly made out, projects southward about 4 miles beyond the general front of the deployed group. This loop may be a part of the Lansing moraine which was not overridden at this point or it may be still older; it has some characters unlike those of the slender moraines of the deployed group. It is not high, but it is more hummocky and more bowldery, being in these respects more like the massive moraines of the Charlotte system to the south. Its relation to the ice-border drainage also suggests that it is alien to the deployed group; it is cut off along its northern side by a large river channel which comes out of Lapeer County and runs southwest close along the front of the overridden belt to Fowlerville, in northwestern Livingston County.

East of Grand Blanc, in eastern Genesee and western Lapeer counties (Davison, Atlas, Elba, and Hadley townships), the relations of the moraines are very simple. The Fowler moraine is the first which can be traced into Lapeer County continuously and without uncertainty as to its identity. In this stretch the Fowler and two earlier moraines are deployed in open parallel lines and seem to stand in simple consecutive order. If this is the true relation then one running past Elba, which stands next east of the Fowler moraine, may be regarded as the Lyons moraine, and the next which runs past Hadley as the Portland moraine. There is, however, a possibility that the relations are not so simple as they seem, for at Goodrich some high morainic knolls which seem to stand apart from the front of the ridge which passes Elba on the west are probably related to a glacial drainage line which issues from the moraine that runs past Hadley and which passes about 11/2 miles southeast of Elba. But it is also possible that the knolls are projecting points of a moraine which was overridden by the later of these ridges; other knolls in Lapeer County stand 2 miles or more southeast of Elba between these ridges. This alternative, though possible, is improbable, for elsewhere overlapping produces a jumbled, confused morainic topography and not an extremely simple one like that here formed.

TOPOGRAPHY.

ALTITUDE.

From the apex of the lobe near Lake Odessa to the west line of Lapeer County is a distance of 80 to 90 miles. If the deployed moraines marked the side of a simple lobe the range in altitude on each individual moraine from the apex to Lapeer County would probably be considerable. But the valley of Flint River caused the formation in Genesee County of a broad subsidiary or side lobe which bulged out toward the southeast, and this tended to lower the moraines slightly in the eastern part of the district. For so great a distance the range in altitude is relatively small, being due partly to the Flint sublobe and partly to the fact that the Saginaw lobe here deployed on a nearly flat plain.

All the moraines rise, though not uniformly, from the apex of the lobe to the west line of Lapeer County. Their lowest parts are all at or near the apex of the lobe, and their highest parts are in the northwest corner of Oakland County and near the northeast corner of Genesee County. In northwestern Oakland County several knobs rise 1,000 feet or more above sea level. All of these appear to belong to the front of the deployed group in the belt of overriding, but may really be slightly earlier with the front of the deployed group laid up against their lower slopes. The general altitude of the morainic knolls in the same area is about 950 feet.

The altitudes given below for the general crest level of the moraines are based on scattered measurements, mostly by aneroid barometer, and are not those of the highest knobs. The values stated are therefore not precise but rather general in quality.

Altitudes on moraines of deployed belt.

Moraine.	Apex.	West line of Lapeer County.	Rise.
	Feet.	*Feet.*	*Feet.*
Lansing	[a] 875	950?	?
Grand Ledge	[a] 880	950?	?
Ionia	[a] 870	950–1000?	?
Portland	820	950	130
Lyons	740	890	150
Fowler	740	870	130
St. Johns	730	850	120
Flint	740	890	150
Owosso	740	860	120
Henderson	730 / [b] 680	?	?
West Haven	720 / [b] 680	?	?
Chesaning	[b] 680	?	?

[a] Overridden east of Lansing. [b] Water-laid.

Water-laid moraines in general have somewhat less relief than land-laid forms. Some of them may also have been more or less reduced in altitude by wave erosion. The uncertainty of their identity east of Flint River gives no chance for certain determination of their altitudes at the meridian of the west line of Lapeer County nor of the amount of rise. The confusion of the overridden

moraines east of Lansing also leaves in doubt the altitude and amount of rise of the individuals in that area.

The altitude of the moraines along the axial line through the successive positions of the apex are of course dependent mainly on the character of the ground over which the ice lobe advanced. From 875 or 880 feet altitude at the apexes on the Lansing and Grand Ledge moraines the altitude drops about 200 feet to the Chesaning moraine, but the greater part of the drop is in the later water-laid moraines which pass below the former lake level. The lower relief of the moraines deposited at the edge of the ice where it stood in lake water contributes something to this difference. A north-and-south line through Owosso crosses all the moraines except the Lansing. The distance is shorter than on the axis and the difference of altitude is a little greater, for the general level of the overriding moraine 5 miles east of Lansing is a little above 900 feet.

The axis of the Flint Valley protrusion was about on a line running northwest and southeast through the city of Flint, and the altitude of two or three of the moraines preceding the Flint is slightly lower near this axis than to the southwest or the northeast. The St. Johns moraine, for example, has a general crest altitude of 875 to 880 feet in the northern part of T. 5 N., R. 5 E. (Argentine Township), and of only about 780 feet in the northwestern part of T. 7 N., R. 8 E, (Davison Township). A lake stood in front of the ice at this stage with its outlet 3 miles north of Linden at an altitude of about 850 feet. Then from the relatively low axis of the Flint sublobe all the moraines rise toward the high morainic area of southern Tuscola County. North of Otter Lake an altitude of over 900 feet is reached on the Otisville moraine.

RELIEF.

The relief of the moraines of this group is generally low, averaging about 20 feet above the plain in front of them and generally somewhat less above that behind them. Their relief, however, in much of their course is considerably less than this, and in some intervals, as from Riley eastward in Clinton County and in southern Gratiot County, it is entirely absent. The water-laid fragments are mostly without noticeable relief.

Where the moraines are developed as distinct individuals without overlapping no point was found with a height of more than 60 feet above the plain and few points above 45 or 50 feet.

In the region of overriding the relief becomes greater, in not a few places reaching 80 or 90 feet, and in some reaching more than 100 feet. This applies especially to the belt east of Lansing and to the Otisville and other moraines in northeastern Genesee County. The normal relief of these moraines, however, is distinctly lower than that of the bulkier moraines and becomes greater only where several ridges are heaped up together.

CHARACTER.

Where they are openly deployed, these moraines are generally smoother than the bulkier moraines and show fewer knobs and basins and other irregular surface features. They show comparatively little evidence of drainage issuing from the ice while they were making, and perhaps on this account their crests are less broken and irregular. The general flatness of the plain on which they were deposited is probably the principal cause of their comparatively even trend and broad curvature.

In the region of overriding many of the forms developed are remarkably irregular and some of them are almost fantastic. Such forms appear at several places east of Lansing, northeast of Otisville, and particularly in the moraine-rimmed circular basin near Duplain.

STRUCTURE OF THE DRIFT.

THICKNESS.

Throughout most of this district the thickness of the drift averages about 100 feet, but varies locally from practically nothing to 300 or 400 feet. (See Pl. II, in pocket.) Near Grand Ledge in northeastern Eaton County, and through northern Ingham County into northwestern Livingston and southern Shiawassee counties, the drift is in many places thin and in some is interrupted by outcrops of bedrock. Bedrock is also exposed in the Grand River channel about 3 miles east of Ionia. But in general the drift in Ionia, Clinton, Shiawassee, and Genesee counties is 100 to 150 feet in depth, and in the counties which border these on the north it is still deeper. A bored well at Saranac, 8 miles west of Ionia, goes 247 feet to rock, which is there but little more than 400 feet above sea level. This well seems to penetrate an old valley in the rock surface which opens to the northwest and is 150 to 200 feet deep. The present surface of the country, however, gives not the slightest evidence of such a depression in the rock.

COMPOSITION.

In its composition the drift of the district is mostly rather uniform on the visible surface but varies considerably as revealed in deep sections and in well borings. For a depth, say, of 40 to 50 feet, the drift is predominantly clayey with a yellowish or buff color and in places with a tinge of brown. The deployed moraines are composed mainly of this clay. They carry comparatively few bowlders and are notably stony only in some parts of the district of overriding or where they were washed by lake waves.

On the high ground bordering the Grand River channel many sections in the bank and many well borings reveal a thick bed of sand or gravel beneath 50 to 100 feet of till. Both east and west of Ionia the north bank about 85 feet above the valley floor contains a great mass of gravel, though in the town tough clay occurs at that level. Many borings in other parts of the district reveal beds of sand or gravel beneath the surface till or intercalated

between beds of till. In the district east of Lansing most of the bored wells get water which contains enough petroleum to give distinct odor and taste.

Many of the borings penetrate in the deeper parts a bed of "hardpan," or dark-colored indurated till, generally very stony, from a few feet to 80 or 100 feet thick, and commonly separated from the bedrock by 2 or 3 feet of open, clean gravel in which the best water supply is found. The dark indurated till appears to be distinctly older than the Wisconsin drift. In places it shows cemented ferruginous bands and other evidences that suggest weathering. But the "hardpan" is not so thick in this district as it is in some of the neighboring counties east and west.

The percentage of crystalline material from Canadian sources is relatively small in the surface parts of the drift; probably more than 90 per cent of the general drift mass being derived from the Paleozoic rocks, mostly from near-by sources.

In several places, as below the asylum southwest of Ionia and at the brickyards 2 miles east of Lansing, pebbleless clays, evidently deposited in lake waters, appear to have been overridden by later ice advances. Those near Ionia are deeply buried under till. Those east of Lansing are overlain by thin, patchy till with bowlders. It seems probable that the lake waters in which these clays were deposited were temporary local bodies of relatively small extent.

ASSOCIATED TILL PLAINS.

The deployed slender moraines lie in roughly parallel lines, except in the region of overlapping east of Lansing, and the intervals between them vary from 1 to 6 miles in width. The till plains which lie between the moraines are long narrow strips of irregular width and are generally typical of their kind. They are plains of clay, more or less pebbly and stony, and have generally a smooth surface which, although flat and apparently level, is nearly everywhere slightly inclined in one direction or another.

The inclination of the till plains depends chiefly on the general slope of the region. Under normal conditions of deposition in a flat region the terminal moraines are heaped up in ridges and the till plains slope gently backward from them in the direction in which the ice retreated. The surface of each till plain is therefore normally highest at the inner edge of the moraine with which it is associated and lowest immediately in front of the next succeeding moraine. The terminal moraine is a heaped-up marginal deposit of till, and the till plain or ground moraine is a subglacial formation spread in a smooth and relatively thin sheet under the weight of the moving ice. The till plains are composed mainly of bowlder clay, but they have few bowlders on their surface or in the sections that show their structure.

The till plain in front of the Lansing moraine slopes gently southward. This plain belongs to the heavier morainic belt (Charlotte morainic system) south of the deployed group.

The till plain on the inside of the Lansing moraine has no well-defined general direction of slope but is inclined slightly in different directions in different parts. The remainder of the till plains back to the shores of glacial Lake Saginaw all slope gently back from the moraines with which they are associated, except in a few localities, such as south of St. Johns, where the plain slopes south and thus guided a glacial river through a gap in the Fowler moraine. After passing through this moraine, the river crossed the next till plain inside the Lyons moraine instead of going northwestward to the Grand River channel south of Matherton. For 10 miles west of Bancroft the Lookingglass glacial river flowed in the till plain of the Lyons moraine, most of the way close back of the moraine rather than farther north.

The till plains are all essentially the same in the remainder of the district back to the beaches of glacial Lake Saginaw. In the eastern part of Genesee County the shallow basins across which the moraines were built led to the formation of shallow glacial lakes like Davison and Kersley (pp. 252, 254), where the till plain dipped to a lower level along a part of its length.

Below the Arkona beaches the slender moraines are water-laid and on that account present little or no contrast with the till plains; and further, they were nearly leveled by the severe wave erosion.

The whole region below the Arkona beaches is a plain without prominent features, the higher parts carrying scattered bowldery patches marking the remains of moraines. The lower part outside of the Port Huron morainic system and comprising the central part of Saginaw County is a plain of faintly laminated lake clays, containing few pebbles or coarse material. In texture they are waxy and apparently as fine grained as cocoa butter. Shafts sunk for coal mining have passed through these clays at a number of places, one at St. Charles penetrating them to a depth of 90 feet.

ESKERS.

BURIED MASON ESKER.

The Mason esker attains its best development in the region south of this district, and that part is described by Mr. Leverett. (See Pl. VIII, p. 208.) It reappears in full strength on the north side of Cedar River in the southeast part of Lansing. A short distance north of the river it appears to be overridden and partly buried under till. Both north and south of Michigan Avenue the troughs on its sides are filled with till and its gravel ridge is nearly level with the general surface. About a mile farther north, at Sheridan Street, it reappears in normal relations as a gravel ridge 20 to 30 feet high and 100 to 200 feet wide, with swampy troughs on both sides. About a mile to the north it heads in two or three short branches.

On both sides of Michigan Avenue, where the esker troughs are filled with drift, large pits were opened many years ago for gravel and sand. Most of the pit walls were old and covered with talus at the time of the writer's visit, so that no good sections showing the structure of the deeper parts were found. Sand is a large component throughout, but considerable coarse material is present in the upper layers, and several crystalline bowlders arid two or three large blocks of much disintegrated bituminous coal were seen. The largest coal bowlders were 2 feet or more in diameter and many smaller pieces occurred in the upper layers. The deeper parts, so far as shown, appeared to consist of horizontally bedded sand of about the grade used for making mortar. The upper layers were not so distinctly bedded.

The front of the Lansing moraine runs toward the northeast through secs. 30 and 20, Lansing Township, crosses to the north side of Grand River at the Logan Street Bridge, and runs thence east through the southern part of the city, crossing the river again just below the junction of Cedar River. West of the bridge it occupies both sides of the river, but in the city it is not very strongly developed. It is somewhat stronger on the east side of the river between the river and the esker. The trend of the moraine to this point carries it directly to the overridden part of the Mason esker and it seems certain that it was the Lansing moraine that overrode the esker ridge and filled the troughs on its sides.

East of the buried section of the Mason esker a small flat plain about half a mile wide forms a recess between the esker and a high morainic ridge to the northeast. This seems like a till plain, but it originally carried many bowlders. The unmodified part of the esker, with its lateral troughs running north from Sheridan Street, was probably formed at the time of the Lansing moraine, for it shows no effects of overriding. It seems probable, therefore, that the ice front rested on the flat plain east of the esker but deposited only bowlders at that place.

Beds of laminated brick clays lie on both sides of Michigan Avenue, about 3 miles east of the State capitol. On the north side, the clays are about 10 feet deep and though they appear to contain no stones, they are contiguous to stony ground that suggests a thin overlying layer of till. The time and circumstances of the deposition of this small body of lake clays were not definitely determined, but probably they were laid down in a local lake formed south and east of Lansing by an obstruction of the Lansing channel southwest of the city. (See p. 251.) If, however, they are buried under stony till it is not clear whether the overriding was done by the Lansing or by the Grand Ledge moraine, for the high moraine just back of the clays to the northeast appears to belong to the Grand Ledge moraine rather than to the Lansing.

The Mason esker seems to end in the southeast part of sec. 3, Lansing Township, and it does not reappear farther north except in a few small fragments. The trough, however, which runs northward in well-defined form as a swampy depression from sec. 34 to sec. 4, Dewitt Township, contains several small knolls or ridges of gravel. North of Dewitt, in Olive Township, an esker nearly a mile long, belonging to the time of the Portland moraine, runs north to south in secs. 26 and 35. Thence northward the line of the esker is not continued by a definite trough but is represented by a series of separate swamps lying between the morainic ridges and trending a little east of north.

THREAD RIVER ESKER.

A large and rather irregular esker about 5 miles long, known as the Thread River esker runs southeast from Flint. Its south part lies half a mile or more south of the front of the St. Johns moraine and was therefore formed in connection with the Fowler moraine. Thread River flows in the west side of its trough for a mile or two. Its passage through the St. Johns moraine in sec. 33, T. 7 N., R. 7 E., is typical, the esker being interrupted and terminated on the north side of the break by two large kames. The large kettle hole in the south part of Flint is probably related to the esker trough, although it shows no direct connection.

This esker was made by a subglacial river flowing southeastward along the axis of the Flint protrusion or lateral lobe. Near Flint the esker is worked extensively for gravel for the manufacture of cement blocks and sand-lime bricks; it shows a percentage of gravel larger than that of most eskers in this region.

THETFORD ESKER.

The Thetford esker, which runs south through secs. 5, 8, and 17 in Thetford Township in northern Genesee County, is a sharp-topped, well-formed ridge, apparently related to the Owosso moraine. In the south part of sec. 8 it has a sharp jog to the east. Two or three small kames stand east of its south end.

MISCELLANEOUS SMALL ESKERS.

There are in this district a few other eskers a mile or so in length and a considerable number of shorter ones. One of the most notable lies east of Ovid. The trough which contains it comes from the northeast. In sec. 6, Owosso Township, and sec. 12, Middlebury Township, the trough contains a fine and conspicuous fragment of esker more than half a mile long. Farther west, in sec. 12, Middlebury Township, it contains another esker about three-fourths of a mile long, nearly parallel to the front of the Flint moraine. After cutting nearly through the moraine, the trough runs for some distance nearly parallel with the Imlay channel but finally enters it from the east, pointing downstream, as if influenced by the direction of flow of the Imlay outlet river, though how this could have occurred is not clear.

The east side of the large trough which runs southwest from Owosso through the Flint moraine contains two fragments of eskers. A little farther south and across the Imlay channel three esker-like gravel ridges cut through the St. Johns moraine, two of them running on to the Fowler moraine, 2 miles to the south. A well-formed

gravelly esker over half a mile long runs southwest through the Flint moraine in sec. 31, Clayton Township, Genesee County.

A small, low esker about a mile long runs southeast past the road corners a mile north of Davison, in Genesee County. Several small eskers occur in relation to the expanded part of the St. Johns moraine and also in relation to the Fowler moraine in southwestern Genesee County.

In central Clinton County a number of kames are associated with the irregular moraines. One situated 2 miles northwest of St. Johns is somewhat like an esker, being drawn out to a length of over 2 miles toward the southwest, but is so broad and flat that it seems like a kame rather than an esker.

GLACIAL DRAINAGE.

GENERAL FEATURES.

The drainage associated with the ice border presents considerable variety. During some of the earlier positions of the ice in the western part of the district, the drainage flowed in relatively small channels directly away from the front. At other times it collected in rivers of greater or less size.

The rivers which flowed along the front of the ice are of two types—those that gathered their waters from the ice and land of the immediate vicinity or from areas not far away and those that were the outlets of one or more of the greater glacial lakes. Most of the former class have relatively small and shallow channels, indicating relatively small volume and short duration. Those of the latter are generally much larger and more deeply intrenched, showing large volume and in some parts suggesting longer duration. Of the former class are the Holly, which is the largest, the Lookingglass, the Bennington, and the Butternut channels. Of the latter class are the Imlay channel, with several branches in its western part, and the Grand River channel, which is of truly great capacity and relatively mature development.

Besides these in which the connections and relations are clear, there are one or two fragments of channels which are isolated and the connections of which are problematic. Of this class is the Lansing channel, which is as large or larger than the Holly channel.

While the ice front was retreating across this district and building the slender moraines of the deployed group the amount of sandy and gravelly outwash shed from the front of the ice or brought out by streams issuing from it was relatively small; indeed, in comparison with that which issued from the front of some of the bulkier moraines, it seems extremely small. This, perhaps, is due to a lack of concentration; if all the slender moraines were compacted into one mass and all the outwash concentrated on one line the discrepance might not seem so great.

DRAINAGE SOUTH OF IMLAY CHANNEL.

DISTRIBUTION.

During the formation of the Lansing moraine all the drainage along its front west of Lansing appears to have been directly away from the ice, mainly along the courses of several creeks which flowed southwest. The valleys of the creeks show in some places gravelly terraces or remnants of valley gravels that seem to belong to the time when the ice was present. The creeks occur at intervals of 3 to 4 miles, and most of them, such as Sebewa Greek, Mud Creek, and three or four branches of Coldwater Creek seem to have issued directly from the ice. Streams appear to have issued along the same lines during the building of the Grand Ledge moraine. As a result, they begin at the Grand Ledge moraine and run southwestward directly through the Lansing moraine.

LANSING CHANNEL.

Along most of its front the Lansing moraine shows no evidence of concentrated drainage or of readvance of the ice, but at Lansing it furnishes a striking example of readvance, closing a large channel of ice-border drainage which had been made just before, when the ice front stood a little farther to the north. From the vicinity of East Lansing, a flat valley one-half to three-fourths mile broad, distinctly depressed below the surrounding till plain and floored with sand and gravel, extends westward to the south part of Lansing and on for about 11/2 miles up Grand River to the Logan Street Bridge. This part of the old drainage channel was not overridden at the time of the Lansing moraine. In this old channel Cedar River wanders in many meanders, generally with a sluggish current, and Grand River has wide room to spare. But at the Logan Street Bridge Grand River is suddenly shut in between walls of bowlder clay 30 to 40 feet high and the channel is so narrow that it has no well-defined flood plain. A dam a quarter of a mile below now backs the water up into the narrow part. The banks are steep and the topography of the drift on both sides of the river for about 3 miles to the southwest is distinctly morainic and is in fact a part of the Lansing moraine. The old drainage channel was evidently overridden and completely filled up for some distance west of Lansing.

A large channel of glacial drainage runs northwest from the bend of Grand River at Diamondale, as shown on the Lansing topographic sheet, and expands into a swamp close in front of the Lansing moraine. The Diamondale channel turns a right angle in this swamp and passes westward down Thornapple River. It may be that the buried Lansing channel formerly extended westward and joined the Thornapple channel at this place in the southwest corner of T. 4 N., R. 3 W. (Delta Township). The features suggest this relation, but no certain proof was found.

East of East Lansing the old channel seems to branch, one part coming down Cedar River from Okemos and the other from Pine Lake across the northwestern part of T. 4 N., R. 1 W. (Meridian Township). This is well within

the region of the overlapping moraines, where the relations are complicated. The drainage along the front of this belt will be described later (p. 253).

While the Grand Ledge moraine was building, conditions along the ice front west of Lansing were about the same as at the preceding halt. A few small gravel terraces in Grand Ledge and Lansing and between these places seem to belong to temporary drainage during the building of this moraine, but they are small and fragmentary. The conditions remained the same during the building of the Ionia moraine. There is scarcely any outwash directly from the ice front along any of the three moraines between Lansing and the Grand River channel.

LOOKINGGLASS CHANNEL.

During the building of the next or Portland moraine the outwash directly from the ice in the interval between the Grand River channel and the region of overlapping was as small as it was during the construction of the earlier moraines. However, a river of moderate size flowed along the front of this moraine from Dewitt, following the course of Lookingglass River westward to Portland, thence going northwest for 3 or 4 miles on the present course of Grand River and thence by a cut-off past Collins close against the front of the moraine to the Grand River channel. Its course is well marked by gravelly terraces and a widened valley 20 to 40 feet above the flood plains of the rivers. This stream appears to have continued in the same course west of Dewitt during the making of the next two moraines. It probably abandoned the short cut-off past Collins, 5 miles northwest of Portland, as soon as the ice retreated from the Portland moraine, and thereafter it followed the present course of Grand River to Lyons. As the ice front retreated, the headward parts of this stream fell backward, cutting through successively later moraines, but the stream was unable to find a course westward along their fronts and so continued to follow the Lookingglass River from a point near Bancroft. During the building of the Fowler moraine the headward parts came from northwestern Lapeer County to the headwaters of Shiawassee River east of Linden and thence down this stream to the Lookingglass south of Bancroft. When the ice retreated to the St. Johns moraine, the drainage reached back along the front of that moraine to the outlet of the Davison glacial lake about 3 miles north of Linden. This lake filled a long, narrow trough in front of the St. Johns moraine, extending northeast at least as far as the north side of Davison Township, Genesee County, and received tributaries from the northern part of Lapeer County.

BENNINGTON CHANNEL.

This last arrangement, however, was short lived, for the river soon found a new course. Instead of following the Lookingglass west of Bancroft, it continued northwestward along the front of the St. Johns moraine to a point 3 miles southeast of St. Johns. Here it left the St. Johns moraine, and after cutting through the Fowler moraine continued westward to the Grand River channel 2 miles above Lyons. The new course from Bancroft west is known as the Bennington channel. This channel is not large, but is particularly well developed west of Bennington, from which it takes its name. At Bennington it appears to be partly choked with gravels brought into it by three streams, which issued from the ice 2 to 5 miles to the east. During the building of the Fowler and St. Johns moraines the eastern part of this stream flowed along the north or inner side of the belt of overlapping moraines which extends eastward from Lansing.

HOLLY CHANNEL.

During the building of the ridge that passes west of Hadley (probably the eastward extension of the Portland moraine) there was in central Lapeer County a glacial lake which had its outlet southwestward along the front of this ridge. In the southwest part of Hadley Township the old bed of this river is prominent, having a flat, swampy floor one-fourth to one-half mile wide. It was first noted near Holly in Oakland County and called the Holly glacial river and its bed the Holly channel. From the southwest corner of Lapeer County the Holly channel runs south-southwest through Groveland and Holly townships, in northern Oakland County (T. 5 N., Rs. 8 and 7 E.), and Tyrone, Deerfield, Cohoctah, and Conway townships, Livingston County (T. 4 N., Rs. 6, 5, 4, and 3 E.), to a point on Cedar River 2 miles northwest of Fowlerville, a distance of about 45 miles from its head near Hadley. It is particularly well developed in Holly Township. Its course is mostly through a jumbled, broken morainic country, some of which has moderately strong relief. Through this the river wound deviously, in places through narrow passages between high hills, as in the eastern and western parts of Holly Township, and in places over broad flats where it laid down extensive deposits of gravel and sand, as in central Holly and central Deerfield townships. Its character and continuity are unbroken to the point near Fowlerville and it has evidently not been overridden by a later readvance of the ice east of there. Its relation to the general slope of the county, which declines toward the northwest, and to a number of streams which flow in that direction across it and through some of the moraines north of it, establish its relation to the ice front very clearly.

Kersley Creek, for instance, rises in the high morainic hills south and east of Ortonville, flows northwest across the Holly channel, through the Hadley ridge and three other moraines and across the drainage channels or lake beds in front of them, and finally reaches Flint River 3 miles north of Flint. Another branch of the same stream crosses the channel and the Hadley ridge in western Groveland Township and joins the main creek near Goodrich. In Tyrone, Deerfield, and eastern Cohoctah townships several of the headward branches of Shiawassee River flow northward across the Holly channel and through the moraines to the main river, which follows the course of glacial drainage westward along the front of the Fowler moraine. East of Cohoctah Township the belt of jumbled moraines extends about to

Goodrich and is only 3 or 4 miles wide, being bounded on the north by the drainage channel along the front of the Fowler moraine and on the south by the Holly channel.

Some channels of glacial rivers throw a more certain light on contemporary positions of the ice front than do the moraines, especially where the course and continuity of the latter are doubtful. It seems entirely certain, for instance, that when Holly River was flowing the ice front rested close along its north side, at least from Lapeer County to the north-central part of Livingston County, for if the ice had stood farther toward the south the site of the channel would have been buried under ice, and if it had stood much farther north the river would have turned in that direction along the course of some of the creeks that cross it and would have escaped westward on a lower and more northerly line.

The fragment of old channel at Lansing may be a continuation of the Holly channel, which it resembles closely, especially as the Cedar Valley seems a natural course westward from Fowlerville. The Lansing channel was closed, as described above, by a readvance of the ice front to the Lansing moraine, but the Holly channel in Lapeer County runs along the front of the Hadley ridge, which seems to correlate with the Portland or fourth moraine farther west. Hence the Holly channel can hardly be earlier than the Hadley ridge which supported it. For this reason it seems certain that the Lansing channel is not a part of the Holly but is probably a fragment of an earlier channel which has been overridden and obliterated entirely east of Okemos.

The closing of the Lansing channel west of that city by a readvance of the ice to the Lansing moraine indicates a preceding recession of the ice front for at least 2 or 3 miles. But the character of the Lansing channel—its magnitude and relative strength of development—coupled with the fact that it seems to be entirely overridden in the eastern part of the area, are still more significant in their bearing on conditions immediately preceding the building of the Lansing moraine. The size of this channel indicates a large river, as large or larger than the Holly. Its source must have been as far back as Lapeer County, where the Holly channel gathered most of its waters, and the Lansing fragment lies only a little lower. It looks like an earlier drainage line of which the Holly is a later revival on a slightly different course. Lansing River probably drained substantially the same area, but its course, not far north of the Holly, has been overridden and obliterated. It evidently marks a somewhat longer interval of time than that which separated the successive slender moraines of the deployed group, and it indicates a greater readvance than that which closed a few miles of the channel west of Lansing.

The fixing of the time of the Holly glacial river as coincident with the formation of the Hadley ridge raises the question as to whether some or all of the slender moraines earlier than the Hadley ridge or Portland moraine may not be present south of the Holly channel. But no evidence favoring this interpretation was found. When the ice front rested on the high moraine east and south of Ortonville it had free drainage southeastward into the interlobate area of that time at a level over 200 feet higher than the Holly channel just north, and no certain evidence of later moraines nor of ice-border drainage was found on the slope down to the channel. If the ice front paused in its retreat down this slope, it made no distinct moraines and left no trace of ice-border drainage. The absence of drainage channels, however, is not by itself conclusive, because the interlobate area in Lapeer County may have drained southward along the east side of the "thumb" during this time, and Holly River may have been the first diversion of that drainage to the west side.

On the other hand, if the slender moraines of this group mark a pronounced readvance of the ice front, as is perhaps suggested by the buried Lansing channel, the first diversion of drainage to the west side may have been along a line farther north than the Holly channel (pp. 252-253), and the channel made then may have been overridden. The drainage line may then have been pushed up the slope to the position of the Holly channel by a readvance to the Hadley ridge.

ELBA CHANNEL.

During the building of the Lyons moraine, which is next later than the Portland, drainage from Lapeer County passed southwestward along the front of the moraine. Its course, however, was not determined, for the moraine disappears in the overridden belt. The drainage may have reached the Holly channel in Groveland or Holly Township.

The amount of outwash from the morainic deposits in the belt of overlapping east of Lansing appears to be small, being limited to a few kames and to gravels and sands deposited in transverse troughs which seem to be in some sense successors of lines of eskers farther south. Along the Holly glacial river and in the lake region near Fenton and Argentine in front of the Fowler moraine considerable areas of gravels and sands are found, but these appear to have been gathered and deposited mainly by the rivers flowing along the ice front.

IMLAY CHANNEL AND KERSLEY GLACIAL LAKE.

When the ice front retreated from the St. Johns moraine a great river suddenly made its appearance and flowed westward close along the front of the Saginaw lobe from a point near Flint to the Grand River channel at Maple Rapids and thence along the course of Maple and Grand rivers to glacial Lake Chicago, which it entered a few miles southwest of the city of Grand Rapids. This river came thus suddenly upon the scene when the retreat of the ice opened a new outlet for the glacial Lake Maumee near Imlay in eastern Lapeer County. The new river was several times larger than any of those previously described in this district, its floor being generally a mile or more in width though somewhat narrower in a few places. From its head to Maple Rapids this old river bed is called the Imlay channel.

When the river first began to flow, the ice front was resting on the Flint moraine, or probably on a line a little farther north that was overridden by a readvance of the ice, but it kept its course along the front of the Flint moraine westward from Flint to a point southwest of Owosso only while the ice rested on that moraine. When the ice front drew back to the Owosso moraine the outlet river broke through the Flint moraine at Flint and followed the front of the Owosso moraine on a line farther north. The channel which it made in this new position, however, is not so deeply trenched nor so well defined, apparently because the fall of the stream and velocity of current were less west of Flint than they were when the ice rested on the Flint moraine. It is, however, fairly well defined from a point north of Vernon westward past Corunna to Owosso. The depression continues past Elsie but shows less evidence of scour west of Owosso.

Running through the Flint moraine southwest from Owosso there is a broad, flat transverse valley containing fragments of an esker on its east side. During the development of the Flint moraine this was an esker trough, probably marking a strong line of drainage issuing from the ice. The Michigan Central Railroad passes through it. That part of the Imlay channel which runs west from this trough to Maple Rapids is generally wider and otherwise suggests somewhat longer use than the part east toward Flint. The western part may be called the Ovid section and the eastern part the Vernon section. The Vernon section is one-half to two-thirds of a mile wide, and the Ovid section extending west from the Owosso esker trough is fully a mile wide at all points.

The explanation of this difference is perhaps to be found in the Owosso esker trough. During the building of the Owosso moraine a considerable part, though probably not all, of the river turned out of the Owosso channel at Owosso and passed southwest through the esker trough back to the Ovid section of the original channel, thus causing this part of the channel to be used longer and made wider than the Vernon section.

At its first flow the outlet river entered Genesee County through two or three distributary channels passing near Richfield and Davison, and formed a long, narrow lake, extending from Richfield southwestward to the vicinity of Duffield. This may be called Kersley glacial lake, after the principal creek that flows across its bottom. The outlet of this lake appears to have been at first just north of Duffield, but by erosion to have retreated eastward 2 or 3 miles. This is the head of the Vernon section of the outlet channel and it was used only so long as the Kersley glacial lake existed.

With further retreat of the ice the river abandoned the Owosso channel and continued northwest from Flint to Flushing, where it entered early Lake Saginaw. At this time it entered Genesee County northeast of Richfield and flowed thence west past Genesee and Flint to Flushing and appears to have flowed for a considerably longer time in this course than in any of the earlier parts farther west.

The distributaries near Richfield and Davison are very immature river channels and were evidently occupied for only a short time. Northeast of Davison the southern distributary is partly obstructed by three or four drift knolls which were standing as islands in the river when it ceased to flow. They were apparently carved by the stream out of a morainic ridge. A large distributary flowed west through northern Richfield Township and was joined in the western part by another from the north. The northern distributary which flowed westward along the present course of Flint River soon became dominant and determined the later course of the outlet river and the present Flint River. The part of the channel extending from Lapeer County to Flushing is considerably wider and more deeply trenched than the parts west of Flint. It also developed more extensive valley gravels which now form terraces above Flint River.

GRAND RIVER CHANNEL.

GENERAL FEATURES.

The Grand River channel is the largest and most deeply trenched glacial river channel in Michigan and is one of the finest in the glaciated area of North America. The deeply trenched part extends from a mile or more above the village of Maple Rapids to 5 or 6 miles southwest of the city of Grand Rapids, a distance of about 75 miles. By later erosion the head retreated about 16 miles farther east to the swampy divide north of Bannister. The part more particularly described here extends from this divide to Saranac. The floor of the channel is 1 to 11/2 miles wide and shows abundant evidence of having been scoured by a great river. Above Lyons, where the modern Grand River enters, the channel is now occupied only by Maple River, a relatively small, sluggish stream which is lost on the swampy floor throughout its whole course from 2 miles northwest of Bannister. The channel floor to Lyons is mostly a very stony, bowldery old river bed, strongly indicating prolonged scour. Some few bars of gravel or sand that rise 10 to 12 feet above the swampy floor are distinctly due to the action of a great westward-flowing river.

In the lower part of its course between Lowell and Grand Rapids the channel is more deeply depressed in the drift than toward its head. At some points its bottom lies more than 200 feet below the country level a mile back, although the bluffs which form the immediate banks are in few places over 120 feet high. Maple Rapids is on a terrace 25 to 30 feet above the channel floor, but the general country level in that vicinity is 50 to 60 feet above the floor. Where the moraines are cut off at the channel 2 or 3 miles east of Maple Rapids the bluffs are 80 to 90 feet high at some points.

The relations of the slender moraines of the deployed group to the Grand River channel show clearly that practically all of the channel was excavated after the building of the moraines. The gently curving lines which the moraines take in bending around from east and west courses on the meridian of Lansing to north and south

courses where they cross the channel show that the floor upon which the ice moved was smooth and without any important depression transverse to its front. All the moraines except the Owosso (pp. 243, 257-259) cross the channel with little or no change in their trend.

EARLY HISTORY.

During the deposition of the early moraines of the deployed group the Grand River channel was a shallow, ill-defined depression in the surface of the drift. But though it was shallow at first, the drainage from the ice and the near-by land gathered into it and soon began to develop a definite river bed. As has been pointed out above, there was no concentration of drainage on the south side of the channel during the deposition of the first three moraines. On the north side there was rather strong drainage along the ice border at all stages of the ice front, but it did not follow the ice front all the way to the line of the Grand River channel during the formation of the earlier moraines. It turned off at points 10 to 20 miles north of Ionia and ran southwest down the course of Dickenson Creek and Flat River to the line of the Grand River channel at Lowell.

On the south side of the channel south of Ionia the plain between the Grand Ledge and Ionia moraines for 1 to 2 miles back from the bluff is covered with a thin coating of gravelly out-wash which was evidently deposited before the excavating of the deep channel was begun. Its western part lies in front of the Grand Ledge moraine as this runs northward along the east side of Berlin Township and may be outwash from the ice front at this halt, but its main body forms an apron-like front to the Ionia moraine. From this moraine it slopes westward with decreasing coarseness.

It is possible, however, that this deposit belongs to the Portland moraine and was deposited by a river coming from the north along the course of Prairie Creek. The valley of this creek seems to indicate previous occupation by a larger stream, and there is a small gravel deposit on its east bank north of Grand River. In this case it may be assumed that a large part of the original deposit was cut away by the later making of the Grand River channel.

A small gravel deposit on the brow of the bluff at the north end of the channel which passes Collins was probably deposited by the first flow of the Lookingglass glacial river, which skirted the front of the Portland moraine. Another small deposit in this channel just east of Collins probably marks a late stage of this moraine, when the drainage was first diverted toward Lyons.

No distinct evidence of outwash was observed in connection with the Lyons moraine; drainage from the north at that stage probably continued to follow the course of Prairie Creek. At this stage the Lookingglass glacial river broke through the Portland moraine east of Collins and joined the line of the main channel at Lyons.

During the making of these moraines the channel along the line of drainage westward had been progressively deepening eastward as the ice withdrew, and the advent of the larger volume of the Lookingglass glacial river no doubt augmented this process.

On the south side of the channel at Matherton a very well defined fan of outwash, deposited on the edge of the plain, indicates the absence of any distinct channel there at that time. The drainage which made this deposit appears to have come from the north, but it may have issued directly from the ice.

INCURSION OF THE IMLAY OUTLET RIVER.

Prior to the formation of the great Imlay outlet the volume of drainage gathered along the line of the Grand River channel was relatively small and the channel produced was of correspondingly small magnitude and depth. When the Imlay outlet river first began to flow it entered the line of the Grand River channel just south of Maple Rapids. At that time the outlet river had a small lakelike expansion just west of Duplain. In the east side of this a large gravel deposit occupies the position of a delta, but seems rather to have been an island-like obstacle in the flow of the river, the current dividing around it with the larger part passing around the north side. It is oval in form and stands 10 to 15 feet above the swamp. Along its west and north sides a prominent gravel ridge runs like a parapet and closely resembles a beach ridge made by waves; from this there is a steep descent into the swamp which stretches away to the west. A narrower channel passes around its south side. This deposit seems more like a kame than any other type—a kame deposited in a small reentrant of the ice front and shaped partly by the ice with which it was in contact and perhaps partly by the later river current. It seems impossible to explain its peculiarities on the supposition that it is simply a delta.

Southeast of Maple Rapids the river appears to have entered a shallow basin and deposited a thin gravelly delta. East of Maple Rapids and resting against the front of the Flint moraine another bed of gravel, much coarser and thicker, appears to have been shed directly from the ice front or else brought in from the east along the eroded bluff. For several miles west of Duplain the Flint moraine is represented by only a few scattered knolls; either it was not formed or else it was washed away by the outlet river. In this interval the channel is nearly all a swamp.

With the advent of the outlet river the increase of volume must have been sudden and great, so that the preexisting river bed along the line of drainage westward was much too small. In its first rush the great river must have torn away the banks of the then existing channel and made a new bed suited to its volume. In doing this it must have swept along a great amount of sediment, and it may possibly have deposited the gravel on the bluff south of Matherton, south of Ionia, and 2 miles west of Lyons in its first rush. The deposit south of Matherton in particular might have had such an origin; the others are thin and flat and appear to have been laid down by small rather than great volumes of water.

RELATION OF THE GRAND RIVER CHANNEL TO THE COURSE OF THE MORAINES.

Early moraines.—As already noted (p. 256), the early moraines show scarcely any tendency to project westward out of their even curves where they cross the Grand River channel. Except in the case of the Lansing moraine at Lansing, no very pronounced evidence of readvance has been found among them; and if the Lansing moraine is the foremost one of a distinct group its readvance may not signify a normal habit for the slender moraines in general but may mark only a readvance after a relatively long backstep in the general glacial retreat.

Owosso moraine.—East of Maple Rapids, however, there seems to be no escape from the conclusion that there was some readvance. The Flint moraine, like all the older moraines of the deployed group, comes up to the Grand River channel on the south side without showing the slightest evidence that any channel or depression was present to influence the movement of the ice, and it seems to pass on to the north with the same general trend. East of the Flint moraine, however, another moraine runs eastward past Union Home and Eureka, forming a high bluff along the south side of Maple River where the head of the Grand River channel widens to the east. (See fig. 1, p. 258.) This fragment is of irregular form and is out of adjustment with the Flint moraine. It runs westward into the head of the channel.

On the north side of the channel a strong, continuous moraine runs south from Ithaca, turning southwestward into the head of the channel, to a point opposite Maple Rapids. (See fig. 1.) This part of the moraine projects westward through the Flint moraine, as though a depression had led the ice to flow a mile or two farther west during the building of the Owosso moraine than it did during the building of the Flint moraine. Such a depression can be accounted for only as the work of the Imlay outlet river immediately before the readvance to the Owosso moraine, and the sharp ice tongue which pushed its point westward to Maple Rapids can hardly be explained except on the supposition that its axis followed a pronounced depression.

The events leading to this result are conceived to have been about as follows: When the ice withdrew from the Flint moraine to some point a little farther east than Eureka, the Imlay outlet river rushed in westward along the front of the ice and cut the channel back several miles eastward from Maple Rapids. Then on its readvance to the Owosso moraine the ice pushed into the newly extended head of the outlet so as to project a tongue 5 or 6 miles westward beyond the even line of curvature which it would otherwise have had. And further, as it readvanced the ice pressed the outlet river up the slope to the south; until it closed the channel again and forced the river back to its course westward from Duplain. Then, while restored flow by this course was going on, the ice built the moraine from Eureka west. Finally, when the ice receded from this moraine, the outlet river rushed again into the narrow passage along the ice front and cut away a considerable part of the north side of the new moraine. The other part of this moraine, extending southward from Ithaca into the head of the channel, was not modified in this way, for no river of any size flowed southward between it and the ice.

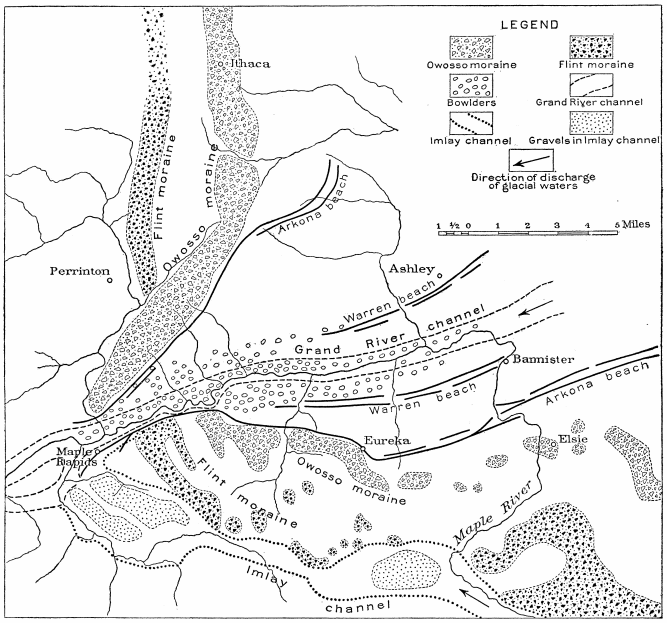


FIGURE 1.—Map showing relation of Flint and Owosso moraines to the Grand River channel.

This rather complicated history seems clearly indicated by the form and relations of the Owosso moraine in this locality. The particular form of discordance seen in this moraine is precisely of that character which requires the supposition of an axial trough or depression for the ice to enter in order to produce the tongue—a depression which was obviously not there when the Flint moraine was made.

Although shore lines exist along the north or back slope of the Owosso moraine, the cutting west of Eureka seems much greater than can be ascribed to waves. For several miles east of Eureka the moraine seems to be cut away entirely. The part north of Maple Rapids was attacked by waves in the same way but was not comparably eroded. The conclusion seems plain, therefore, that it was the return of the outlet river to a course close in front of the ice, when the ice began to withdraw from the moraine west of Eureka, that caused the heavy cutting along this part.

These facts seem to establish beyond a doubt a movement of readvance to the Owosso moraine amounting to at least 4 or 5 miles, and as no reason can be assigned why there should have been a readvance to the Owosso moraine more than to others of the deployed group, there is a possibility that a similar readvance preceded the building of each one of the slender moraines. If oscillations with moderate readvances like this characterized the whole group the fact is highly important in the discussion of all glacial and climatic questions and theories.

Henderson moraine.—A mile or two east of Bannister a faint bowldery belt having a northwest trend forms the watershed between Saginaw Bay and Lake Michigan. This belt, which apparently marks the course of the Henderson moraine (the next following the Owosso), shows no tendency to bend westward into the Grand River channel. The ice front did not form a tongue like that of the Owosso moraine, for at this stage the moraine lay on flat ground a little east of the head of the channel. That the outlet was not cut back to this position seems certain, from the fact that though the outlet river was active for a relatively long time after the ice had retreated permanently from this vicinity, there is now only a very shallow broad depression on the divide. The original divide was farther west.

TERRACES IN THE GRAND RIVER CHANNEL.

In addition to the relatively small, thin gravel deposits associated with the moraines at the top of the bluff (p. 256), a complex set of gravelly terraces and bowldery benches occurs along the sides of the Grand River channel. The principal gravelly terraces are from 15 to 45 feet above the channel floor, but some fragments are found at higher levels.

East of Matherton, on the south side of the channel, a well-defined bowldery terrace, evidently at one time part of the channel floor, now stands slightly above it for over 2 miles. About 2 miles above Lyons one of the finest terrace fragments in the valley runs along the north side of the channel for about 3 miles and is 30 to 35 feet above the swampy floor.

Between Matherton and Maple Rapids there are two islands in the old outlet channel, or rather one long, narrow island broken by a cut that does not reach to the bottom of the present channel. The island is a little over one-half mile in width at its east end, but in a mile narrows to less than one-fourth mile, and west of the transverse trough decreases still more, being at its extreme west end only 250 or 300 feet wide. The island is a remnant of the original till plain and is flat topped, with an altitude of 50 to 60 feet above the channel floor. Just west of Maple Rapids the channel divides in equal parts around this island, Maple River passing now on the north side. Hayworth Creek enters the south channel south of the east end of the island and runs northeast on the swampy floor to Maple River just below Maple Rapids. Islands like this are common at the head of most glacial outlets. In this particular place the early flow of the Imlay outlet river appears to have started the channel on the south side and a smaller stream that on the north, both at levels considerably above the present channel floor; subsequently the outlet river occupied and deepened both.

ALLUVIAL FANS.

After the Grand River channel was abandoned by the outlet river every stream that came into it began to build an alluvial fan. Above Lyons all the fans are small and the channel floor is very bowldery and swampy, scarcely any of it being fit for cultivation. At Lyons Grand River has built a large alluvial fan, which extends up as well as down the channel for some distance; it is this deposit that has crowded Maple River over against the north bank at Muir. Stony Creek has done the same 2 miles above Muir. The fan at Lyons also keeps Grand River to the north side of the valley for a mile or two west. From Lyons westward the lower parts of the channel floor have been silted up by the river, leaving only the tops of gravel bars and a few bowldery patches projecting, thus turning much of the floor into arable land, which is, however, subject to overflow.

What has been said above concerning the Grand River channel refers only to its earlier and relatively small volume drainage and to the early work of the Imlay outlet river. This covers only the early part of the development of the great channel. For a relatively long time after these two stages the channel was occupied by the outlet river of the Huron-Erie glacial lakes, and it was then that the principal work was done in deepening and widening it to its present large dimensions. This part of its development and history is discussed in connection with glacial Lake Saginaw. (See pp. 360-361.)

GRADIENTS OF THE GLACIAL RIVERS.

After the retreat of the ice sheet the northern part of the region of the Great Lakes was affected by differential uplifts or warpings of the land. These movements are recorded in a wonderful way by the tilting of the old glacial-lake shore lines, which, although horizontal when they were made, are no longer so but rise gently toward the north or northeast. The uplifts and their effects on the old shore lines are discussed later (pp.430, 461, 502-518). So far as known the southern part of the lake region was not affected by the uplifts, the old shore lines in that part still remaining horizontal. The dividing line between the affected and the unaffected areas is therefore not a nodal line, as it has sometimes been called, but a “hinge” line, the lands only on the north side having been affected.

The isobase of zero or the “hinge” line of the early deformation (see p. 342), which affected Lakes Maumee, Arkona, and Whittlesey, passes about west-northwest 4 or 5 miles north of Birmingham, Mich., from the middle of Lake St. Clair. The beaches of the Saginaw basin show that it extends in the same direction through that area. South of this line is the “area of horizontality,” in which the beaches show substantially no deformation. All the drainage lines mentioned, excepting a little of the Imlay channel in eastern Genesee County, lie in this unaffected area. The gradients of the channels in this area therefore do not now differ from those which they had when they were made.

The head of the Holly channel in Hadley Township, Lapeer County, has an altitude of about 940 feet. About 2 miles west of Fowlerville, beyond which its identity is uncertain, it has an altitude of 880 feet. It therefore descends about 60 feet in a distance of about 45 miles.

The head of the Lookingglass channel was at the outlet of glacial Lake Davison, 3 miles north of Linden, where the altitude is about 850 feet. At its western end, where it entered the Grand River channel 2 miles northwest of Collins, its altitude is about 740 feet; the descent is 110 feet in about 70 miles. When the course of this river shifted to the route along the St. Johns moraine and down Stony Creek, the altitude at its mouth 2 miles east of Lyons was about the same as before, but the distance had been reduced to about 60 miles.

The highest Maumee beach in Goodland Township, Lapeer County, has an altitude of about 855 feet. The outlet river entered Genesee County at an altitude of about 800 feet, was at about 790 feet at the outlet of Kersley Lake near Duffield, entered the Grand River channel south of Maple Rapids at about 710 feet, and at Ionia was at approximately 700 feet. It probably included a glacial lake in Lapeer County in addition to the Kersley glacial lake in Genesee County. This gives a total descent of about 155 feet in 120 miles. But the head of the outlet was a little over 30 miles north of the hinge line in the direction of greatest uplift and the altitude there is about 55 feet higher than the highest Maumee beach in the area of horizontality (p. 342), so that about 55 feet must be subtracted from the present descent of the channel to find the actual descent at the time the river was flowing, and this would leave about 100 feet for the total descent in 120 miles.

At the time of the middle Maumee beach the altitude at the head of the channel was about 25 feet lower, or 830 feet above sea level, and the river then entered Lake Saginaw at Flushing, where the lake level was about 710 feet. But Flushingis about 12 miles north of the hinge line, and allowing 45 feet for uplift gives a descent of 75 feet in about 52 miles.

The Grand River channel was at first about 75 miles long, extending from the Arkona beach near Maple Rapids, with an altitude of about 710 feet (aneroid), to the upper beach of Lake Chicago west of Grand Rapids, with an altitude of about 640 feet. It therefore descended about 70 feet in 75 miles. The floor on the divide north of Bannister is 72 feet above Saginaw Bay (652 feet above sea level), and when the channel extended back to the Warren beach in this vicinity its altitude was about 675 feet. The second beach of Lake Chicago has an altitude of about 620 feet, and the descent was therefore about 55 feet in a distance of about 100 miles. If Lake Chicago fell to its third beach while the outlet was flowing the descent would be about 75 feet in about 110 miles, for as the lake level fell in Lake Chicago the shore moved farther west from Grand Rapids.

It is thus seen that the rate of descent of these glacial rivers was generally less than 1 foot per mile, the highest rate being less than 11/2 feet per mile and the least a little more than one-half foot per mile. It is worthy of note that the channel with the lowest gradient was occupied longest.

INTERLOBATE AREA ON THE "THUMB" OF MICHIGAN.

By FRANK B. TAYLOR.

GENERAL FEATURES.

The moraines bend around the great interlobate angle on the "thumb" from northeast-southwest courses in western Lapeer and south-central Tuscola counties to northwest-southeast courses in western Sanilac County, and to north-south or east of south courses near the forty-third parallel in southeastern Lapeer and northwestern St. Clair counties. The first two or three of the moraines turn more sharply than the later members of the group. They run a little east of north in southwestern Lapeer County and a little east of south in the southeastern part. For these earlier members the bisecting line or axis of the apex of the interlobate angle runs a little west of north. With the later moraines the axis shifts to north and a little east of north.

The acuteness of this interlobate angle is relatively moderate. In other parts of the region the margins of two lobes at times faced each other directly and were partly in contact; sharply contesting for possession of the narrow strip of dumping ground between them; such conditions .produce the most remarkable of the interlobate morainic deposits. On this part of the "thumb," however, the opposing margins were not in contact at the stage of recession under consideration. The first of the slender moraines curves gradually around an intervening open space nearly 20 miles wide at the south side of Lapeer County and 12 miles wide at the village of Lapeer, north of which it follows almost a semicircle. The angle grows less and less acute with the later moraines. A few of the moraines appear to be continuous around the reentrant, but others are represented by scattered fragments or are in a more or less tangled condition.

PRE-WISCONSIN RIDGES.

Outcrops of pre-Wisconsin till near East Dayton and the numerous reports in well records of hard till beneath the relatively soft Wisconsin drift at various points and especially in elevated places show that the older drift is present in large amount and that it forms the nucleus of some of the prominent ridges and knolls.

North of Mayville a group of large, irregular drift masses has a relief of 100 to 150 feet. The largest mass is in T. 11 N., R. 10 E. (Dayton Township), and runs a mile or two into the eastern part of T. 11 N., R, 11 E. (Fremont Township). As a whole it is roughly triangular in shape, measuring over 3 miles from north to south and about 7 miles from northeast to southwest. To the northeast, beyond a plain one-half to three-quarters of a mile wide, another smaller mass of the same character appears, lying mostly in sec. 31, Kingston Township, but partly also in Koylton, Wells, and Dayton townships. This has its eastern end a mile west of Kingston. South and east

of Kingston other masses with very irregular forms rise rather abruptly out of a flat clay plain. The shapes and configurations of these drift masses and the absence in the particular localities of a converging ice movement to produce interlobate ridging suggest pre-Wisconsin age. Confirmation of this interpretation seems to be found in the presence of 75 to 100 feet of hardpan in deep wells located on these ridges and of outcrops of it on some of the steep hillsides and in ravines. One outcrop appears on a hillside slope about three-quarters of a mile west of East Dayton, and another a mile farther north along the bed of Sucker Creek. The hardpan is a dark-colored stony till, much harder than the ordinary lighter-colored till of the surface, but in general appearance the same as outcrops of Illinoian till in regions farther south. Borings indicate that the older drift is not limited to these blocklike, somewhat isolated masses but underlies massively a large part of this region. There is reason to believe that it also forms the core or main undermass of a broad ridge which runs from the vicinity of Flushing northeastward to East Dayton and Kingston. The coating of Wisconsin drift on these large older masses appears to be relatively thin. The shapes they take and the depressions associated with them are probably in part due to pre-Wisconsin erosion.

DISTRIBUTION OF MORAINES.

PORTLAND (?) MORAINE.

The outer ridge of the morainic system in Lapeer County is the one already noted that runs near Hadley, in the southwestern part of the county, and is tentatively made the equivalent of the Portland moraine. It runs north-northeast from Hadley to the west branch of Flint River, passing about 4 miles west of Lapeer, and then curves to the east and southeast, passing about 7 miles east of the same city. West of Lapeer the morainic expression is rather gentle, there being a smooth, even ridge 1 to 11/2 miles wide and 30 to 50 feet high. North of Lapeer the ridge is more irregular and reaches a width of 3 to 4 miles and embraces some conspicuous outwash aprons. This strength and width continue southeast to a point 2 or 3 miles west of Imlay. Farther south it is banked against the eastern base of the next earlier morainic system.

LYONS (?) MORAINE.

A second ridge runs near Elba in western Lapeer County and is thought to be the same as the Lyons moraine farther west. It is traceable with more or less distinctness and continuity around the curve in northern and eastern Lapeer County to Imlay. It is nowhere more than 2 or 3 miles distant from the moraine outside of it, and in the north and east parts of the county is generally less than 1 mile distant. In western Lapeer County it is hardly a mile wide, but in northern and eastern Lapeer County, as far south as Mill Creek, it is 2 to 31/2 miles wide. From Mill Creek southward past Imlay it is again weak and finds its continuation in the Birmingham moraine of the Huron-Erie lobe. (See pp. 281-282.)

FOWLER MORAINE AND ASSOCIATED KNOLLS AND RIDGES.

The third ridge of the system in the reentrant angle is continuously traceable westward as the Fowler moraine. It comes from the southwest into western Lapeer County and extends north-northeast up to the south bluff of Flint River 2 miles west of Oregon station. Up to this point it is a strong, prominent ridge, 1 to 11/2 miles wide, with a rather even crest. Beyond this point it has not been identified with certainty.

A distinct till ridge half a mile wide that begins just west of Columbiaville and runs southwest and west along the north side of Flint River may possibly be a part of the Fowler moraine, but the correlation seems doubtful, for the ridge appears to be clearly overridden a mile west of the county line by the Otter Lake (St. Johns ?) moraine. North of Columbiaville there is another east-west ridge less than half a mile wide and 3 miles long, and beyond that a larger east-west morainic tract over 4 miles long and 11/2 miles wide. This last tract includes many kames and short esker ridges, and both this and the narrow ridge south of it are overridden by the same later moraine that overrides the fragment southwest of Columbiaville. If these fragments belong to the Fowler moraine then this moraine extends to the north side of Flint River north of Columbiaville, and its normal course would carry it in a wide curve around the north side of the interlobate area to the east side. But there is a wide gap without morainic deposits where this moraine might be looked for, and it does not seem possible at present to make definite correlations across this space. The three fragments north of the river near Columbiaville seem plainly out of adjustment with the Otter Lake moraine, which overrides them all near the west line of Lapeer County, and they have no certain correlative eastward. Still they may be continued, after an interval of 10 or 12 miles, in the Imlay moraine, which seems to lack westward connections near North Branch, just as the Fowler moraine lacks eastward connections near Columbiaville.

IMLAY AND GOODLAND MORAINES.

The Imlay and Goodland moraines are closely contiguous. They begin about 3 miles southeast of North Branch and trend southeast along the east side of the Imlay channel to Mill Creek. Toward Mill Creek the two crests draw closer and are scarcely separable. South of Mill Creek both ridges are fainter but are more distinctly separated. The eastern one (the Goodland moraine) is faintly double in the southeastern part of T. 8 N., R. 12 E. (Goodland Township), and the western one (the Imlay moraine) has some gaps and short side ridges toward Imlay. The two ridges converge again toward Imlay, where they are about a mile apart. East from Imlay they are each one-fourth to one-half mile wide and are separated by a peat bog. These moraines are described below (p. 285).

A few miles north of Imlay, in the central part of Burnside Township, some large kames stand on the line of these

moraines. They have two principal crests and their longer axes trend with the moraines northwest and southeast, the two main knobs being about a mile apart. (See pp. 271-272.)

OTTER LAKE (ST. JOHNS?) MORAINE.

The Otter Lake moraine lies 1 to 11/2 miles southeast of Otter Lake in northwestern Lapeer County. It comes up from the southwest out of Genesee County and is probably the continuation of the St. Johns moraine. South and southeast of Otter Lake it is strong, being nearly 2 miles wide and composed of four or five minor ridges. East of Otter Lake it is narrower and lower, about a mile wide, and is broken by a large esker which trends southeast.

The features north and northeast of Otter Lake are hard to interpret satisfactorily. Two alternatives are presented. According to one, at a break in the esker about 11/2 miles northeast of Otter Lake the front of the next later moraine overrides the Otter Lake ridge. North of the esker a low, slender ridge, apparently the front member of the minor ridges just mentioned, comes up from the south and connects with two morainic spurs which project about a mile southeast. According to the other interpretation, a well-defined morainic belt, running northeast directly in line of prolongation of the Otter Lake moraine to a point 2 miles south of Mayville, forms the front of the complex morainic belt that extends eastward along the northern boundary of Lapeer County.

The available evidence seems to favor the first alternative; in that case the lower morainic deposits east of the esker and the morainic belt, running northeast from this point, all belong to the Otisville moraine rather than to the Otter Lake, and the Otter Lake moraine is overridden east of Otter Lake by the Otisville moraine. So far as known, the Otter Lake moraine has not been recognized at any point farther north or east.

OTISVILLE MORAINE.

As just described, the Otisville moraine passes just north of Otter Lake and thence apparently northeastward to a point 2 miles south of Mayville. In secs. 21 and 28, Watertown Township, its course is interrupted by a drainage channel bearing a stony deposit, partly morainic and partly resembling small kames. Stony morainic spurs that run out a mile or more to the southeast on both sides of the small stream which flows from Cedar Lake toward Fostoria seem distinctly older than the moraine and are partly overridden by it. To the northeast in Water-town Township the moraine is about a mile wide and is separated from the next moraine to the west by a fairly distinct, narrow bench—not a depression but a line of change of altitude and topography.

For 5 or 6 miles along this part of the moraine a sandy out wash fan overspreads the clay plain, covering nearly all of Watertown Township that lies southeast of the moraine and running south into Marathon Township for a mile or more.

From a reentrant angle in the moraine south of Mayville gravelly outwash spreads southeast for a mile or two, east of which a narrower and weaker morainic ridge runs eastward with front convex to the south. Two miles northwest of Silverwood this ridge sinks beneath sandy outwash from the next later moraine but is apparently continued about 2 miles east of Silverwood by a moraine of about the same strength and character, trending southeast, which emerges from the east side of the outwash deposit.

After emerging from the outwash apron this moraine passes just south of Clifford and continues southeasterly into T. 9 N., R. 12 E. (Burnside Township). It is very much broken and toward Burnside becomes an irregular belt of scattered knolls. In secs. 5 and 6, Burnside Township, the channel of a glacial river from the northeast breaks through the moraine in a westward course to the Imlay channel south of North Branch. Southward from this drainage line as far as the southeast corner of Burnside Township the scattered deposits continue, but south of this along the county line the country is a wide, flat swamp with only a few knolls rising 2 to 4 feet above it. A line of faint knolls answering this description passes from the southeast corner of T. 8 N., R. 12 E. (Goodland Township), southeasterly into T. 7 N., R. 13 E. (Mussey Township), St. Clair County, where it meets a large transverse ridge extending toward the southwest. In Burnside Township the eastern knoll of “Deanville Mountain” stands about in line with this moraine but probably belongs to the next earlier moraine. The relations in this vicinity, however, are not certain.

DEANVILLE MORAINE.

West of Index a slender, even-crested moraine, here called the Deanville moraine, runs directly south past Deanville and in broken form to Mill Creek at the county line. Beyond, in the western part of the township of Lynn, lies a great swamp, in which nothing representing this moraine was observed. Beyond the swamp, however, in the line of trend of the moraine produced from where last seen south of Deanville, a faint ridge continues to the southeast in northeast Mussey Township. Another fainter, more broken ridge runs parallel with this about a mile to the east. These faint ridges begin near the south side of one of the transverse ridges which cross this region from the northeast. On the north side of this transverse ridge two morainic knolls stand in about the trend of the Deanville moraine, but their longer axes are parallel with the transverse ridge. The relations of this moraine are not clear. It appears to be older than the Mayville moraine, but its connections toward the north and west are not known.

MAYVILLE MORAINE.

The Mayville moraine appears to be a continuation of the Flint moraine. It enters Watertown Township, Tuscola County, in secs. 30 and 19 and extends thence directly northeast to Mayville. In most of this interval it is high and rugged and nearly 2 miles wide. At Mayville it turns

more easterly, bending south a little, like the Otisville moraine, which is a mile or so south of it. Gradually it turns southeast, passing 11/2 miles northeast of Clifford, runs east nearly to Marlette, turns again southeast, bending east at the county line 3 miles southeast of Marlette, and thence runs east to the northeast corner of Lapeer County. At this point it is broken by a swampy trough which runs north along Cass River and southwest to the Imlay channel south of North Branch. Whether it finds its continuation southward in the Deanville moraine or eastward in a chain of morainic knolls connecting with the Owosso moraine northwest of Omard remains undecided, though the Deanville line seems the more probable.

OWOSSO MORAINE.

A moraine regarded as the probable northeastward extension of the Owosso moraine passes 11/2 miles southeast of Millington (p. 243) and runs northeastward to Murphys Lake as a low, smooth ridge one-half to three-fourths of a mile wide. Northeastward from Murphys Lake it runs along the inner base of the Mayville moraine, not in the form of a ridge but banked up against the earlier ridge as a belt of morainic ground with a definite drainage line along its upper edge. North of Mayville it connects with a group of large irregular drift masses that resemble interlobate deposits, but which, as already noted (p. 261), seem to be largely pre-Wisconsin drift.

Half a mile to a mile south of East Dayton knolls of sand and fine gravel 20 to 25 feet high cover a considerable part of the surface but end abruptly at the north base of the higher ground in secs. 9 and 10. The higher ground is all stony till with no outwash covering. Just west of the corner at East Dayton a small drainage trough runs southwest.

The sand knolls and the little drainage trough seem to be products of border drainage at or near the front of the ice when the front rested on or against the north slope at East Dayton. Many kames and sandy deposits southeast of Cat Lake, in secs. 17 and 18, are probably associated with streams issuing from the ice in that depression.

YALE MORAINE.

On the east side of the interlobate tract the Owosso moraine apparently finds continuation from the vicinity of Kingston in an ill-defined, very much broken line of low morainic knolls which run southeast through northeastern Koylton, central Marlette, and central Flynn townships to the vicinity of Omard. The broken, faint character of the morainic forms in this interval leaves their identity and correlation somewhat uncertain. However, a better-defined moraine, known as the Yale, appears 3 or 4 miles northwest of Omard and, passing a mile west of this place, continues in better form southeast into Speaker Township. It passes a mile southwest of Speaker as a strong ridge with its front slightly concave to the southwest. Just opposite Speaker it crosses at right angles one of the large transverse ridges of this region. To the south for a mile or two its expression is faint, but near Yale it begins again as a well-developed ridge and runs south along the east side of Mill Creek into Kenockee Township, where it becomes water-laid.

JUNIATA MORAINE AND BOWLDER BELT.

From Millington a faint suggestion of a moraine extends northeastward toward Juniata. West and northwest of Murphys Lake it is manifested by low morainic knolls and south and east of Juniata its place is marked by low bowldery knolls and ridges. In secs. 15, 16, and 17, Fremont Township, there is another morainic mass with kames; and in secs. 1, 2, and 3 of the same township and north along the east side of secs. 36 and 25, Indian Fields Township, there is a high, narrow, rugged ridge which is mainly morainic but which contains also two or three kames of large size. Some of the gravels here are overlain by till, having been apparently overridden by a readvance of the ice.

A well-defined bowlder belt associated with this moraine becomes prominent about a mile northeast of Juniata, and runs thence northeast past the large kames just described and across Wells Township into Novesta Township, where it turns eastward past Deford and Novesta and extends a little way southeastward into Evergreen Township, Sanilac County.

There seems to be no doubt that much of this bowldery belt marks the position of the ice front during the building of the Juniata moraine, although it is also associated with a great drainage line which followed the front of the ice for a brief time and entered Lake Saginaw, probably south of Juniata.

For 12 miles northeastward from the southwest corner of Wells Township no definite morainic ridge was observed. In the central part of Novesta Township, however, a strong morainic ridge runs northeast, crossing into Sanilac County from sec. 36, Elkland Township. Possibly this is the northeastward continuation of the Juniata moraine, but, although it lies in the trend of this moraine, such a correlation seems uncertain, not only on account of the wide interval, but because the deposit as a whole seems to be more of the nature of an interlobate moraine.

INTERLOBATE DEPOSITS AND SCATTERED RIDGES IN SANILAC COUNTY.

In Evergreen, Greenleaf, and Austin townships, large irregular masses of stony till which seem to show no particular trend or arrangement, except on the east and northwest sides, are cut up into irregular patches by a number of branching and interlacing glacial channels and spillways. On the east and northwest sides they lie closely parallel with the front of the Port Huron morainic system and are separated from it only by the channel of the outlet of Lake Whittlesey.

Along the east side a range of hills runs north-northwest about 7 miles from the middle of Minden Township across the southwest corner of Pans Township to the

center of Bingham Township, Huron County. Although parallel with the front of the Port Huron system, this range of hills shows forms that bear some resemblance to drumlins; in fact, it is made up of smooth, oval hills with their axes coincident with the trend of the group. Other isolated hills of this type stand in eastern Austin Township. The larger hills reach a height of 50 to 60 feet. These hills are not perfect drumlins, but a few of them fall little short of typical forms. The occurrence of drumlins or drumloid hills in this angle in front of the Port Huron system finds a complement on the Canadian side of this same ice lobe which makes for symmetry in a very striking way, viz, near Clinton, Ontario, a considerable number of small but well-formed drumlins stand in front of a reentrant angle in this same moraine. The angle, however, is not acute like that on the "thumb."

In Sanilac County west of Black River, east of the moraine last described and south of the interlobate area in the northwestern part, scarcely any morainic features appear. Almost the entire area is a flat clay plain, and only a few small fragments, none of them more than a mile or two in length and few more than 20 feet high, can be classed as morainic. Eskers, kames, and transverse ridges are more prominent than morainic features. The fragments appear to be scattered without arrangement or order, except near Shabbona, whence a series of low clay knolls runs south and southeast into Moore Township, and after an interval of 2 or 3 miles is perhaps extended in more knolls of the same character running south 3 or 4 miles from Elmer; these knolls, however, are so small and scattered that it is doubtful whether they mark a halting place of the ice front. From Lamotte eastward and southward along Cass River is another broken line with low knolls, which may be morainic, but which, from their composition, seem more like a broken esker or a line of kames. (See p. 270.)

TRANSVERSE RIDGES.

In southern Sanilac and northwestern St. Clair counties and in less degree in northeastern Lapeer County several ridges lie directly across the trend of the moraines and in places are crossed by moraines in such a way as to show that they are the earlier. They are composed largely of clay with large numbers of bowlders, and some of them have associated gravel and sand deposits. Two or three seem to be composed mainly of bowldery clay, but have a veneering of assorted material partly in the form of kames and partly a flat surface covering.

One of the largest transverse ridges, 40 or 50 feet high and more than a mile wide, runs south-southwest from the middle of Washington Township, Sanilac County. After a swampy interval of 4 miles it reappears, in southeast Elk Township, as an irregular line of ridges connecting southward with an extensive kame area near Melvin in central Speaker Township. Here it turns west-southwest and is crossed by the Yale moraine, which appears to be distinctly younger. From the crossing it runs in a remarkably straight course to Mill Creek in sec. 7, Lynn Township, St. Clair County. In this last interval it carries large numbers of bowlders and contains also much gravel.

Another transverse ridge, parallel with the one just described, begins in the northeast part of Buel Township, where two ridges of smaller size lie close together. Beyond a gap of about a mile it reappears as a prominent ridge running southwest, passes west of Buel, and crosses northwest Fremont Township into eastern Speaker Township, where it too is crossed by the Yale moraine.

At the bend of Mill Creek 2 miles northwest of Yale two ridges seem to start from the same point. One, which is notable for its bowlders, runs west to the termination of the ridge just mentioned, in sec. 7, Lynn Township. The other and stronger runs south for 6 miles and then turns southwest on a nearly straight line toward Almont, dying out toward the southwest in sec. 31, Mussey Township. Just north of the southwest section of the ridge the shorter fragments parallel with it and one longer fragment which seems to converge southwestward with it.

Other features, apparently of the same kind but smaller, lie in Lapeer County. One runs southwest from Brown City toward the Deanville kames and is probably related to them. Another runs southwest through Burlington Township to the Imlay channel, a mile north of North Branch.

The origin of the transverse ridges can not be fully explained at present. It seems clear, however, that they are related in some way to strong lines of drainage in or under the ice, and are therefore in a certain sense analogous to eskers, although not of typical esker form. The one that runs southwest from Melvin and the one which converges with it from the east seem to have found their southwestward prolongation up the valley of Mill Creek through Goodland Township and in a general way toward the interlobate angle, when that angle was acute and was situated on the high ground of southern Lapeer County. The other large ridge points in a general way toward the same place. It is conceived that these ridges were produced not by sub-glacial streams but by streams whose positions were inherited from lines of drainage which led to the interlobate angle when the ice front was in southern Lapeer County, and that the ridges themselves were developed at a later time when the ice front had receded to the Imlay or the next later moraine and had become relatively thin at the margin, so that the streams encountered dirty basal layers of the ice.

TOPOGRAPHY.

ALTITUDE AND RELIEF.

The moraines of this district do not show much variation in altitude, excepting in the southern part of Tuscola County between Otter Lake and Kingston. When the ice front rested on the high moraines at the south edge of Lapeer County the interlobate angle was acute and the

front lines of the two lobes faced each other almost directly. At the time of the building of the outer two moraines the ice front had dropped from its high position to the plain of central Lapeer County and the acute angle had opened out and become nearly a right angle. At the time of the building of the later moraines which bend around the north side of Lapeer County the angle had changed to a curve, at first a semicircle but later more open, with a sweep of 20 to 25 miles. Though the area considered here is in a broad sense interlobate, at the particular stages discussed true interlobate conditions of deposition did not exist, for there was no conflict of opposing or converging ice. The front curved gradually from one lobe to the other around a wide unoccupied area throughout which normal conditions of marginal deposition prevailed. At only one or two places did small local reentrants in the ice front cause a heaping of deposits from two sides. This relation—a broad curve instead of a sharp angle—naturally led to the making of moraines with more even crest altitudes than would otherwise have been built.

In western Lapeer County the crests of the outer two moraines have altitudes 880 and 890 feet above sea level, only a few small areas reaching 900 feet; their relief is seldom more than 50 or 60 feet, with an average of 35 to 40 feet. In central Lapeer County these two moraines are developed in much greater strength, some knolls rising to 960 feet, though the general altitude is about 900 feet. From Flint River in Rich and Deerfield townships southeastward to Imlay the altitude is mostly 900 to 950 feet. In many places the relief is 80 to 100 feet and in two or three over 150 feet. The Otter Lake moraine rises to about 925 feet south of Otter Lake and has a relief of 50 to 60 feet.

The Mayville moraine between Otter Lake and Mayville forms the most extensive high ground in the district, much of it rising above 900 feet and one hilltop a mile west of Mayville above 1,000 feet. Two areas in central and southeastern Dayton Township rise above 940 feet and one small area in southern Koylton Township above 900 feet. The Owosso moraine rises from about 780 feet south of Murphys Lake to about 850 feet near East Dayton; its relief varies from 20 or 30 feet at the south to 50 or 60 feet at the north. Except on the high kames in central and northeastern Fremont Township, the Juniata moraine has an altitude of 770 to 780 feet.

The relief between Otter Lake and Mayville is the greatest in the district with the exception of the Deanville kames mentioned below. (See p. 271.) Relief of 80 to 100 feet is common and the rise from Murphys Lake to the east 11/2 miles is 200 feet or more. In the high areas of Dayton Township the relief is 100 to 150 feet. Except for two or three points that rise to 50 or 60 feet in Fremont and Indian Fields townships, the Juniata moraine has scarcely any perceptible relief and in the bowldery belt in Wells and Novesta townships lacks what little it has elsewhere.

In northeastern Lapeer and southwestern Sanilac counties the moraine crests rise above 900 feet in a few places but are mostly between 850 and 900 feet. The Deanville kames rise at their summits to about 1,030 and 1;060 feet, respectively (aneroid). The two highest knobs are 1 mile and 11/2 miles from the Imlay channel, which has there an altitude of 790 feet, and they therefore rise above it about 240 and 270 feet, respectively. These are the highest points on the "thumb" north of the high area at the south line of Lapeer County.

The interlobate deposits in northwestern Sanilac County for the most part rise but little above 820 feet, though a few points reach as much as 850 or 860 feet. The relief generally is not more than 40 feet. The scattered ridges in Sanilac County have altitudes mostly between 775 and 800 feet, and their relief ranges between 10 and 30 feet. The transverse ridges have crest altitudes of 800 to 850 feet with relief ranging between 10 and 50 feet.

CHARACTER.

Up to the middle of Oregon Township the outer two moraines are relatively even, smooth ridges, with mild swell and sag topography, but as they turn northeast into Mayfield and Deerfield townships they become much more irregular and varied. One of the finest types of swell and sag topography seen in this part of Michigan is on the road running 2 miles southeast from Columbiaville. In northern Mayfield, southern Deerfield, central and western Arcadia, and northern Attica townships, especially in the last three, the outer moraine shows knob and basin topography. In northwestern Attica the development is more pronounced, especially north of Attica station. The deposition of the drift in the belt between Attica and central Deerfield was considerably influenced by waters issuing from the ice. Probably three-quarters of the area between these points is of a somewhat irregular swell and sag type, but much of it consists of small plateaus with undulating surfaces, like those in northern Attica and southern Arcadia. The second or Lyons moraine from the bend of Flint River, in the southeastern part of Rich Township, is similar to the outer moraine in its topographic expression but has some higher kames close to the Imlay channel, and for 6 or 7 miles north of Imlay it has a more pronounced development of knob and basin topography. Some of the basins 3 or 4 miles to the north are large and deep.

The narrow ridge running southwest from Columbiaville on the north side of Flint River is of smooth swell and sag type.

The Otter Lake moraine is composed of several parallel ridges close together with rather strong swell and sag expression and some basins. The morainic ground in north-central Marathon Township is associated with large esker ridges and has irregular topography. It has knobs and basins, two or three of the basins being rather large. South of this area a small till plain is inclosed like a basin by a sharp narrow bowldery ridge 15 to 25 feet high which extends around its south and east sides.

The Otisville moraine is very rugged north of Otter Lake and has many knobs and basins associated with the esker formation. The rest of this moraine to the neighborhood of Silverwood has a moderate swell and sag topography. Southeastward into Burnside Township, if its identification there is correct, it has mainly a swell and sag topography, but with some pronounced basins.

The Mayville moraine has a great development of knob and basin topography in western Watertown Township in association with the esker trough leading south from Murphys Lake. The rest of this moraine to the east line of Dayton Township has a strong swell and sag topography but includes many basins, some of them on its highest parts.

The Owosso moraine has a rather mild swell and sag topography as far as a point north of Mayville, except along its outer border, where it has knobs and basins in association with the gravels of the Butternut border drainage line. Farther northeast, on the high ground of Fremont and Dayton townships, it has a varied expression, mainly swell and sag, but with knobs and basins along its front, especially southeast of Cat Lake.

In areas where it has little relief, the Juniata moraine is mainly swell and sag, but in each of the three areas where it has strong relief it has more or less knob and basin topography, especially in the largest high area in northern Fremont Township.

Near Marlette the Mayville moraine shows mostly swell and sag topography on the ridges, but in some places it has many basins and on its inner border many swampy hollows.

The Deanville moraine is a smooth ridge along its front but is bordered by scattered irregular knolls for a mile or two on its eastern side.

The ill-defined morainic belt running east through southern Koylton has mainly a swell and sag topography, but has also a considerable number of basins and many swampy recesses on its inner side. This expression continues nearly to Omard, but beyond that the form of the Yale moraine is mainly swell and sag to the kame area in the central part of Speaker Township, where knob and basin topography and kames are developed in connection with the overriding of the large transverse ridge.

The ill-defined morainic belt running southeast from Kingston and the high area just west has some knobs and many basins.

The interlobate region in northwestern Sanilac County has a broad swell and sag topography with a moderate development of drumlin-like forms in the eastern part.

Almost all the scattered ridges in western Sanilac County are low swells. Some, however, are sharp and narrow, but these more or less resemble eskers.

The transverse stony ridges are mainly smooth, with only mild swell and sag forms, but where their tops bear kames they are rougher and have many basins. Where they are crossed by the moraines they have also a mixed topography.

STRUCTURE OF THE DRIFT.

COMPOSITION.

The moraines of the district are composed mainly of stony clay, the proportion of bowlders and pebbles being considerably greater than in the moraines west of Lapeer County. The more pronounced interlobate deposits in central Lapeer County, especially those south of the Imlay channel between Oregon and Imlay townships, contain a very large share of coarse materials. The moraines in this interval approach more nearly the interlobate type, in which more or less concentration of coarse sediments is characteristic. The moraines in Marathon and Watertown townships also contain much coarse material, but the group of moraines that sweep through southern Tuscola County around into Sanilac, eastern Lapeer, and northwestern St. Clair counties are more largely composed of clay. Except in their higher parts, the Owosso and Juniata moraines are composed largely of clay with very little coarse material.

The transverse ridges are composed mainly of very stony till, bowlders being generally very plentiful upon them. Considerable quantities of gravel and sand are associated with these ridges in places, especially upon the tops of the larger ones in Washington and Elk townships.

No very extensive sand or gravel deposits were found. The outwash apron in Watertown and Marathon townships is the largest. Two or three smaller ones occur in central Lapeer County.

Between the Arkona beaches and Cass River a large share of the surface is covered with fine sand. The Arkona beach ridges are composed of gravel, but the Warren beach is generally sandy.

Borings have not disclosed any thick or extensive beds of gravel or sand beneath the surface sheet of till. Almost invariably they find the whole depth to rock to be occupied by till and hardpan or old till (see p. 261), with only a few thin layers of sand or gravel. The drift in this district strongly contrasts in this respect with that of the high region in the northern part of the southern peninsula, where in many places a relatively thin coating of till covers great depths of gravel or sand.

THICKNESS.

In Lapeer County the thickness of drift ranges from 50 to 200 feet, with an average of a little more than 100 feet. In the morainic belt in southern Tuscola County the thickness is greater, but on the flat plain to the north and on the plains in Sanilac County it ranges from 20 to 120 feet. At Brown City near the Lapeer County line two wells pass through 190 and 213 feet of drift. In northwestern St. Clair County the thickness varies from 150 to 225 feet. Some of the deeper borings probably show the location of buried valleys in the rock surface.

TILL PLAINS.

Till plains are for the most part very broken and patchy. This arises from the confusion and overlapping of the moraines in the interlobate area. The plain in Rich Township, Lapeer County, is perhaps of till, but is covered to some extent with lake clays. A few small till plains occurring in the midst of morainic deposits are quite remarkable, because of their striking contrast to the moraines; such are the one west of Columbiaville, a smaller one to the north, and a small one between Mayville and Silverwood.

The most important till plain of this district, however, is that which occupies a large part of west-central Sanilac County and runs over into Tuscola County in Novesta, Kingston, Ellington, and Wells townships. It lies northeast of the morainic belt, west of Black River and Elk Creek and south of the interlobate district in northwestern Sanilac County, covering 450 to 500 square miles. It contains only a few small fragmentary morainic ridges and a few eskers. Its altitude is mostly between 800 and 850 feet. The drift is relatively thin, varying generally between 20 and 50 feet, is less stony than that of the moraines, and is not covered with lake clay.

Other smaller plain areas of till lie in southern Sanilac and northern St. Clair counties, but are considerably broken by the moraines and transverse ridges.

ESKERS.

LAMOTTE ESKER.

A rather remarkable esker 11 miles long stands on the till plain of western Sanilac County. For about 6 miles it runs south in the western tier of sections of Elmer Township along the medial line of a swamp that follows the south branch of Cass River. In this part the esker, which is about 30 feet high, is broken into several pieces, but they are ridge forms and are aligned after the manner of true eskers. In some respects, however, the ridge is not a normal esker, for the fragments contain a considerable amount of till and in places many bowlders. The fact, however, that they are composed also largely of gravel and sand, taken in connection with their form, alignment, and relation to the swamp, seem to show that they are in reality a modified esker.

In sec. 6, Elmer Township, the ridge (tracing it headward) turns sharply northwest and at about 2 miles divides in two branches, one continuing northwest for about a mile and the other running directly west for over 2 miles and turning northwest at its end. This east-west section is a more typical esker. It is more generally composed of gravel and sand and one or two of its knobs rise 60 feet above the surrounding plain.

Another ridge about 3 miles long crosses the county line a mile south of Novesta and extends southeast toward the Lamotte esker. Its gravelly knobs seem more like kames than parts of an esker, but it is in all probability a part of the same formation as the Lamotte esker.

KOYLTON ESKERS.

In the eastern part of Koylton Township two finely formed eskers run southwest and end in a swampy trough which runs south to Clifford. The eastern esker is on the line between secs. 14 and 23, Koylton Township; after following a winding course for over one-half mile west, it turns southwest for 11/2 miles and becomes considerably higher and more bulky. It is an excellent type of esker, 40 to 50 feet high and with very steep sides and narrow undulating top composed of coarse gravel and pebbles.

The western esker, which is not so well developed, runs about 11/2 miles to the same swampy trough. A chain of gravelly knolls running south and curving southwest for about 11/2 miles from Kingston seems like a broken and poorly developed esker.

OTTER LAKE ESKER.

The great gulf in the morainic deposits in the western part of Watertown Township, Tuscola County, contains many kames and some short esker-like ridges. At its southern end, where it emerges on the higher ground, an esker of large size and typical form runs south from the middle of sec. 29 about to the middle of sec. 32. The ridge is 100 to 200 feet wide on top and 70 or 80 feet high, and the troughs on the two sides are ponds of considerable depth. South of this fragment the symmetrical form of the esker is broken for nearly a mile to the middle of sec. 5, Marathon Township, Lapeer County, the break appearing to mark the front of the Otisville moraine at the time the ridge to the north was made. At the break there is some offsetting, for when the esker begins again it runs to the southeast. For about a mile it is not so strong and high and is broken abruptly by a pond in the middle of sec. 9. At the east side of the pond the esker rises sharply to a height of 70 or 80 feet and continues southeastward into a jumble of kames and ridges and morainic knolls which fills a considerable area in secs. 10, 11, 14, and 15. At the east end of this area another short gravelly ridge runs southeast in secs. 14 and 13 to the bank of the Imlay channel, half a mile distant.

OREGON ESKER.

In sec. 13, Richfield Township, Genesee County, a finely developed esker, 50 or 60 feet high with deep troughs along its sides, runs south and, turning southeast across the county line, crosses sec. 19 into sec. 29, Oregon Township, Lapeer County. This esker is remarkable for the way in which it terminates. It passes through the Fowler moraine to the trough in front and there merges abruptly into a small gravelly delta fan, which measures about three-quarters of a mile by half a mile and is typically developed in its relation to the esker.

MISCELLANEOUS SMALL ESKERS.

About 3 miles northwest of Imlay a large gravel ridge nearly a mile long in the trough of Mill Creek resembles much in form and situation an esker, although it is in some respects like a kame. It is higher and wider at its

western end where it emerges into the Lum channel. A number of smaller eskers are situated in various parts of this district. Several short, finely formed eskers are associated with the Mayfield kames.

KAMES.

DEANVILLE KAMES.

A mile and a half west of Deanville, in Burnside Township, Lapeer County, stands Deanville Mountain, a cluster of high kames composed principally of gravel. Many bowlders, mostly small ones, appear in the gravel, and stony till is seen in it in some places, especially toward the base. Like most other kames, these are irregular in outline and have many knobs and basins at different levels.

The Deanville kames are roughly divided into three large masses. The largest mass stands on the east side in secs. 27 and 22; a somewhat smaller one joins it closely on the southwest in southwestern sec. 27; the third lies a mile west of the first, mostly in sec. 28, but partly in sec. 21, Burnside Township. By aneroid measurement from Brown City the eastern knob has an altitude of about 1,060 feet above sea level, the western one 1,030 feet, and the southern one a little less. The divide on the floor of the Imlay channel 11/2 miles southwest of the kames has an altitude of about 790 feet, so that the highest knobs rise about 270 and 240 feet, respectively, above that level. They rise nearly 200 feet above the general level of the surrounding country.

Along the east side of the eastern knob there is a well-marked depression or foss into which the descent is steep. This depression was evidently occupied by the ice and the steep slope marks the contact of the ice mass.

The longer axes of all three hills are northwest and southeast, or in accord with the trend of the moraines, to which they seem to belong. As already noted (p. 263), two well-defined moraines run southeast from about 3 miles southeast of North Branch. Their crests are only a mile apart, but they run as two distinct individuals southeastward to the vicinity of the kames. If the kames were inset a little from the front of the ice, as seems probable, their relations and the interval between them seem to accord well with the two moraines referred to.

At one time the railroad ran a spur from Brown City to the north end of the eastern kame and a large amount of gravel was taken out for ballast. The pit at the time of the writer's visit, however, was old and showed few details of structure, except that it had a great depth of coarse gravel and large numbers of bowlders.

MAYFIELD KAMES.

The Mayfield kames stand in the northwest corner of Mayfield Township, Lapeer County. The highest knob, which reaches an altitude of 950 feet, is in sec. 7, and is adjoined by several smaller kames, especially on the southeast. North and northeast of the high knob a jumbled country of about a square mile is covered with knobs and basins and very pronounced short esker ridges trending northwest and southeast. The highest knob is covered at its top with coarse gravel and pebbles and is steep sided and narrow topped. The lower ground among the esker ridges is unusually rough.

This deposit lies in the trend of the Otter Lake esker and it seems quite likely that it was deposited by the same glacial stream at an earlier stage of retreat.

GOODLAND KAME.

Southwest of the Deanville kames, on the west bank of the Imlay channel, stands the Goodland kame, a double-topped kame of large proportions but of somewhat lower height. From the trend of the moraines this kame appears to have been produced by the same glacial stream that made the Deanville kames, but at an earlier stage of retreat.

About 21 miles northwest of this kame, and standing also on the west bank of the Imlay channel, there is another large kame which reaches about 1,020 feet altitude (aneroid).

JUNIATA KAME.

In the highest part of the Juniata moraine on the north line of sec. 2, Fremont Township, Tuscola County, a large kame known as the Juniata rises considerably above the surrounding country, but its altitude was not measured. It is somewhat elongated toward the southeast. East of this 11/2 miles a broader knob rises still higher and appears to be partly of the nature of a kame but partly morainic. A pit on the flank of this hill showed bowldery till distinctly overlying clean cross-bedded gravels and suggested an overridden kame.

MISCELLANEOUS KAMES.

Some parts of the transverse ridges in Buel and Elk townships, Sanilac County, appear to be largely of the nature of kames, this being especially true of the ridge north and west of Buel, which seems to be composed mainly of kames; it rises 40 to 50 feet above the plain. In northeastern Buel two ridges are evidently kames in part, but they stand at a lower level and were largely modified by wave action at the time of Lake Whittlesey.

A narrow ridge east and northeast of Peck in Elk Township is largely composed of kames. A smaller but quite prominent kame cluster occurs 3 miles north of Peck, and a number of kames stand east and northeast of Melvin, in Speaker Township. Most of these kames rest on morainic ground or stony till. In the transverse ridges the kames seem generally to overlie ridges of stony till, the main undermass being of this composition,

GLACIAL DRAINAGE.

OUTWASH APRONS AND DELTA DEPOSITS.

MAYFIELD OUTWASH DELTA.

The quantity of gravelly and sandy outwash which issued directly from the ice front in this district is surprisingly small, only three or four deposits being of sufficient importance to require mention.

In the northern part of Mayfield Township, 5 or 6 miles north of Lapeer, a small but rather remarkable outwash deposit covers the whole of sec. 10 and small parts of all the adjacent sections. It is surrounded on its east, west, and north sides by a rugged, bowldery morainic deposit, which descends steeply to the lower ground on its inner side. This narrow morainic deposit seems like a retaining wall around the sides of the outwash and appears to represent an ice-contact surface. Except perhaps at a few points on its east side it does not rise above the level of the gravelly deposit.

The exceptional thing about this deposit is the height to which it rises above the surrounding country. Its surface has an altitude of about 960 feet, whereas the till plain immediately south of it and extending to Lapeer has an altitude of 825 to 850 feet. Its top is almost flat, but slopes a little to the southwest, and its sand is notably finer at the south than at the morainic rim.

The formation seems much like a delta formed in a lake and the situation favors that origin. The flat ground north and east of Lapeer seems much like a lake floor and has in fact a deposit of pebbleless lake clay in some of its lower parts. There was, however, a lake on this plain at a later time and the clays may belong to that.

If this deposit was made in a lake it must have been at a slightly earlier stage of the glacial retreat than that represented by the moraine that runs past Hadley and the glacial river that flowed along its border, for the general crest level of the moraine is under 900 feet west of Lapeer and the head of the glacial river near Hadley is not above 840 or 850 feet. Some scattered morainic knolls in and west of Lapeer running south and others 3 or 4 miles east of Lapeer may, perhaps, represent the position of the ice at that time.

This high outwash deposit is one of few deposits which the writer has seen in the West that bear a close resemblance to the “sand plains” described by New England geologists. The outwash apron that bears the university campus and much of the city of Ann Arbor, Mich., is another of this type; it is described by Mr. Leverett in the Ann Arbor folio.

FOSTORIA OUTWASH APRON.

The largest outwash deposit in the district is that which lies around Fostoria in Watertown Township, Tuscola County. It is 9 or 10 square miles in area and lies in contact with the front of the Otisville moraine for about 6 miles. It may have issued from the ice front all along the line of contact, but a considerable part of it appears to have come from a gap in the moraine northwest of Fostoria, where there are kames and much very stony ground with knobs and basins.

The surface of this deposit is quite uneven, especially in its western part, which contains a number of basins. Its eastern part is composed mainly of fine gravel and sand and its altitude along the front of the moraine is 850 to 860 feet. It appears to have been deposited in the border of a shallow lake.

SILVERWOOD OUTWASH APRON.

From the front of the Mayville moraine a plain of sandy and gravelly outwash stretches 11/2 miles south, reaching nearly to Silverwood and extending a mile or two farther south on each side of that place. Its composition grows finer toward its outer edge. For 3 or 4 miles the Otisville moraine appears to be completely buried under this deposit, the upper edge of which has an altitude of about 860 feet.

This outwash apron has some peculiar features. South and southeast of Silverwood its front has a sort of digitate form, several narrow, finger-like ridges of sandy gravel, some of them a third to a half mile long, project south-southwest in straight lines over the flat, smooth clay plain. These ridges are 10 or 15 feet high and have some resemblance to the lobations seen on the fronts of some deltas but are too narrow and too precisely parallel for such an origin to be probable. It has also been suggested that they may have been formed in channels in a dead ice mass which covered the plain. As yet no explanation offered-seems altogether satisfactory. The deposit as a whole, however, appears to have been laid down in a shallow lake.

DRAINAGE SOUTH OF IMLAY CHANNEL.

HOLLY CHANNEL AND LAPEER GLACIAL LAKE.

The headward part of the Holly channel is in Lapeer County near Hadley, and it seems quite certain that central Lapeer County was occupied by a relatively small glacial lake which lay chiefly in Lapeer, Mayfield, and Attica townships and partly in Oregon and Elba townships, and which discharged southwestward through the Holly glacial river. This lake, known as the Lapeer glacial lake, received drainage directly from the ice around the interlobate angle and drainage from the ice border for some distance south on the east side of the high land, the latter probably entering through the channel running north and northwest from Dryden.

ELBA CHANNEL.

The Elba channel is nearly as large as the Holly and was apparently but little lower. The Lapeer glacial lake was shallow when it discharged through the Holly channel, so it is doubtful whether it remained in existence with the lower outlet. There are two or three passages through the Hadley ridge (Portland moraine) which might have allowed the waters to go westward to the Elba channel. One of these is southwest by way of Bronson Lake in Oregon Township, and another through Nipissing Lake

in Elba Township. The even spread of the gravel fan at the end of the Oregon esker seems to suggest still but shallow water for its deposition, or at any rate water with too little current to effect the formation of the fan. The drainage of this area went first past Atlas to the Lookingglass channel and afterward to the Davison glacial lake.

LUM CHANNEL.

The Lum channel is remarkable. It is only a fragment, extending northwest from about 2 miles north of Imlay to Flint River in northern Deerfield Township, parallel to the part of the Imlay channel between Mill Creek and Rich Township. This channel is a mile and in some parts more than a mile wide—two or three times as wide as the narrow part of the Imlay channel. Its banks, especially in its southern and middle parts, stand 70 to 90 feet above its floor; toward the northwest they are lower. From Mill Creek to Kings Mills the eastern bank is a high, rugged moraine, so steep along its front facing the channel that it seems certain that it was undercut by a river.

The significance of this channel in the lake history is largely problematic, for it is only an isolated fragment cut off from direct connection with the only glacial lake that can be supposed to have been connected with it. The river that made it must have been fully as large as the Imlay outlet river, for its proportions resemble those of the larger sections of the latter—those, for instance, between Richfield and Flint in Genesee County. It is one of those suggestive fragments which shows the complexity of the lake history without shedding a clear light on the events connected with its origin.

North and west of Imlay a rather high, bulky moraine has crowded westward into the Lum channel, closing it entirely and cutting off all southward extension, unless one be found in the somewhat doubtful Rochester channel (p. 283). At its northwest end in northern Deerfield Township the Lum channel opens into the Imlay channel, and no certain indication of its course farther west has been found, though it is possible that the extra width of the Imlay channel above Columbiaville represents its continuation. The slope is northward, for railroad profiles show altitudes of 871 feet at Lum and 861 at Kings Mills and both stations are 4 or 5 feet above the channel floor. Toward its south end the floor of the channel contains much outwash, and near Kings Mills it is swampy and covered with peat.

The altitude of the highest Maumee beach at Imlay is 850 feet and near Goodland Church about 855 feet. From this it appears that the Lum channel could have served as the outlet of glacial Lake Maumee only if the land in Lapeer County stood at that time lower relatively to the land at Fort Wayne, Ind., than it did a little later during the operation of the Imlay outlet. In that event it may have become the outlet at the time of an extreme backstep in the oscillations of the ice front, and the beach made then may have been completely overridden and destroyed as far south as Birmingham by the readvance of the ice to the Birmingham moraine. It is this same Birmingham moraine that closes the Lum channel northwest of Imlay and forms the eastern boundary of the Rochester channel farther south.

Although it is not possible at present to make sure of its relations to the lake history, it seems almost certain that the Lum channel, including probably the Rochester channel as a part of the same line, marks the establishment of a full-volume discharge for Lake Maumee before the time of the Imlay outlet and during the early part of the time when the western front of the retreating Lake Huron ice lobe was oscillating back and forth across this critical area. The beach of Lake Maumee, which was the correlative of the Lum channel, has not been identified.

IMLAY OUTLET CHANNEL.

MAIN IMLAY CHANNEL.

General character.—The Imlay channel west of Lapeer County was described in connection with the glacial drainage of the eastern limb of the Saginaw lobe (p. 254). The head of the channel has generally been described as being a mile or two south of Imlay, and it was in fact there during the last stages of Lake, Maumee. But when the channel was first established through eastern Lapeer County its head was 7 or 8 miles farther south, or about at Almont; and this short length of the channel, which really belongs with the moraines of the Huron-Erie slope, may as well be described here.

From Almont to Forth Branch the Imlay channel is bounded on the east by a moraine which, though a slender individual, is nevertheless through most of the distance quite clearly and strongly developed. It forms the immediate eastern bank of the channel throughout this interval and except in one reach between Imlay and central Goodland Township is so closely set against the channel that it seems to have been pressed forward to make the channel more narrow.

The Imlay channel begins to have a definite floor 2 miles east of Almont. The floor is swampy and contains more or less peat and marl nearly all the way from Almont to Imlay and in this interval has a width of a third to a half mile, although at the level of the highest beach of Lake Maumee it is generally a mile or more wide. North of Imlay for 4 or 5 miles the moraine stands back a little to the east, and the swampy channel floor holds a width of about one-half mile. In the central part of Goodland Township the moraine presses in again more closely than before, and the channel continues thence to a point 2 or 3 miles southeast of North Branch with a width of one-third to one-half mile between high, steep bluffs.

The lands bordering the Imlay channel from Almont to Imlay are relatively low on both sides; except for a large knoll running a mile northeast from Almont on the west side and a narrow morainic ridge east of Imlay they nowhere exceed 30 or 40 feet. From Imlay to Mill Creek the banks on the east side continue with the same low relief, but from Mill Creek to the transverse channel

south of North Branch the moraine presses up to the east side of the channel and for 8 miles forms a steep bank 70 to 80 feet high. In this interval the channel is floored at many places with gravel and sand and at some places contains small bars or terraces. The peat on the northern divide is not deeper than 3 feet. On the west side a high, rugged moraine forms a steep bank to the channel through the whole interval to North Branch. The kames described above form the highest points.

From the point where the transverse channel enters the Imlay outlet above North Branch the channel floor becomes wider and the banks somewhat lower. The floor is swampy to a point below North Branch, but through the southern part of Rich Township the banks are lower and the floor is bowldery. On leaving Rich Township the channel turns southwest and keeps this course to the county line. Except for about 11/2 miles above Columbiaville, the channel in this interval is a full mile in width and is floored with sandy gravel. The gravel filling begins near the north line of Deerfield Township, reaching some distance eastward into the mouth of the Lum channel and expanding to a width of more than 2 miles just above the narrows northeast of Columbiaville. In the narrows there is not much gravel, but below Columbiaville the channel widens again to a mile, and the gravel extends to the county line and also some distance up the Elba channel. From Rich Township to the narrows the bed of the modern Flint River is trenched into the gravels about 10 feet. Below Columbiaville the gravels stand as terraces 20 to 25 feet above the river. A mile or two south of the town the terrace on the east side carries a number of basins. The heavy gravel terraces continue to Flint and Flushing.

The origin of the narrows above Columbiaville is not clear. The Imlay channel when first made probably had the average width in this interval, and the expanded portion just above the narrows suggests an obstruction introduced after the first cutting of the channel, probably by a readvance of the ice. As just stated, the wide part above the narrows may be a part of the Lum channel. There are several good-sized kames at the head of the narrows on the south side. It seems probable that some of the marked irregularities of the morainic ridges west and north of Columbiaville are due to readvances of the ice into the westward extension of the Lum channel and that the channel was overridden and obliterated by these readvances.

Between Almont and North Branch there are three low divides in the channel. One is 11/2 miles north of Almont, another 3 miles north of Imlay, and the third 2 miles south of the Deanville kames. All are flat and are covered with peat and would not be noticeable, except that they divide the water in the channel and turn it into different drainage systems.

Gradient.—In order to get an adequate conception of the relation of the Imlay outlet channel to Lake Maumee it is necessary to consider to what extent the northward differential uplift has affected the channel since it was made. In the Ann Arbor quadrangle the highest Maumee beach has an altitude of 800 feet and was affected very little if any by differential uplift. But 4 or 5 miles north of Birmingham it begins to rise northward, and from the vicinity of Rochester it rises at an average rate of about a foot in a mile. This brings the beach at Almont to an altitude of 840 feet and at Imlay of about 850 feet. At Almont, therefore, the beach is 40 feet higher than it is at Birmingham, where it was not uplifted.

The floor of the Imlay channel 11/2 miles east of Almont has an altitude of 796 feet. But since this is 40 feet higher than it was formerly, its altitude before deformation was about 756 feet. East of Imlay the channel floor is about 800 to 802 feet[1] and on the divide south of the Deanville kames it is about the same. At Imlay its altitude was formerly 50 feet lower than now, or 750 feet. The northern divide is about 10 miles north of Imlay, and at the same rate of rise-—a little over a foot in a mile—the original altitude of that point was, say, 60 feet lower than now, or 740 feet. About 11/2 miles south of North Branch the present altitude on the floor is about 785 feet, and this, measured in the northerly direction of the uplift, is about 4 miles farther, so that the floor was originally about 64 feet lower than now, or in round numbers 720 feet.

[1]The altitude of the Huckleberry Marsh in the Imlay channel 3 miles north of Imlay is 808 feet as determined by Mr. Leverett by wye level from Imlay, but a pole can be run down there 10 feet or more in slush, so that the outlet floor is below 800 feet,

It is thus evident that the original fall of the Imlay channel was from about 756 feet at Almont to about 720 feet at North Branch, or 36 feet, whereas the present descent is only 10 or 11 feet. By the windings of the channel the distance is 24 miles, giving an original descent of about 11/2 feet per mile and a present descent of less than 6 inches per mile.

These figures are based on the altitudes of railroads which cross the channel at Almont, Imlay, and North Branch and on aneroid measurements for the northern divide. They are not as accurate as could be wished, but are probably not far wrong.

This part of the Imlay channel is of exceptional interest on account of its relation to the direction of differential uplift. So far as known, none of the other outlet rivers of the glacial lakes nor any of those that ran along the edge of the ice or away from it flowed for any considerable distance toward the north; that is, up the slope of the tilted or uplifted land. Where the course of a river was along an isobase, its rate of descent was not changed by the uplift; where it was down the slope of the uplift, its rate of descent was increased; but where its course was up the slope, its rate of descent was diminished and might even be reversed. Where the uplift increased the apparent descent of the channel neither the existence of the uplift nor its general direction can be inferred safely from the channel alone. But where the descent was greatly reduced or reversed this fact and the general direction of the uplift become evident. This part of the Imlay channel is the only one known that affords a test of this effect of land tilting. The channel is strongly

developed and shows abundant evidence of scour—certainly more than one would expect from a descent of 10 or 11 feet in 24 miles. From North Branch to Flushing the differential uplift increased the descent of the channel 30 to 35 feet. As it is now about 75 feet it must originally have been 40 to 45 feet in about 45 miles.

The relation of the Imlay channel and of the temporary small lakes in northern Lapeer County to Lake Maumee will be discussed later (p. 348).

Readvance of the ice.—It was stated above that a moraine which is tentatively correlated with the Fowler moraine (pp. 262, 275) appears to press westward into the Imlay channel, crowding the river against its western bank. That this is a fact seems to be strongly indicated by the manner in which a later moraine presses against this moraine, especially between North Branch and Mill Creek. Between Mill Creek and the Deanville kames the two moraines are pressed into one mass and can not be distinguished as separate individuals. Between the kames and North Branch their crests are a mile apart and are clearly separate. North of Imlay to Mill Creek they are more lightly developed and very distinctly separated. Southeastward from Imlay they are not in contact at all, but separate more and more widely toward the Macomb County line. In southwestern St. Clair and northwestern Macomb counties they show the spacing of 2 to 4 miles that characterizes the same group of moraines in the Saginaw Valley.

From these facts it seems clear that this part of the Imlay outlet was strongly affected by a readvance of the ice front and narrowly escaped being closed along the line between North Branch and Mill Creek. The pressure was greatest for about 4 miles between Mill Creek and a small brook which descends to the channel from the Deanville kames. These two morainic ridges both show clearly westward pressure or readvancing movements, the first ridge pressing against the channel and almost closing it and the second ridge pressing severely against and partly overriding the first. Yet they are separated by the usual interval east of Almont. The closing of the channel by a readvance of the ice, so narrowly escaped at the time of both of these moraines, had actually occurred at an earlier stage when a readvance closed the Lura channel. In considering questions relating to oscillations and readvances of the ice front, this group of facts connected with the Lum and Imlay channels and associated moraines is of the greatest importance.

BUTTERNUT CHANNEL.

The Butternut channel came in from the northeast as a tributary to the Imlay channel. It ran southwest along the front of the Owosso moraine and had its headwaters apparently in the vicinity of Kingston and East Dayton. In its length of about 25 miles the present channel descends 140 feet—from about 880 to 740 feet. Its course was directly down the plain of the tilted land, so that something like 30 feet must be subtracted to find its original descent of 100 to 110 feet. At its head it drained two or three small lakes, one lying southwest of Kingston and others, probably smaller, in Koylton Township and northeast of Mayville.

In the lower course of the Butternut channel, from a point about west of Otisville, prominent gravel terraces, like those of the Imlay channel, suggest a certain amount of aggradation or filling after the first or most active deepening. This and the strongly marked aggradation of the Imlay channel between Columbiaville and Flint are probably associated with a readvance of the ice front in Genesee County.

EAST DAYTON SPILLWAY.

Although the Juniata moraine is poorly developed except in two or three places, the ice front while building it appears to have formed the northern bank of a large river, known as the East Dayton spillway, which flowed toward the southwest in southern Tuscola County. Its course where it is constricted 2 or 3 miles west of East Dayton is well defined. Its present altitude at this point is about 740 feet. At an earlier stage it probably flowed at a level 30 or 40 feet higher and passed through central Fremont Township to the sandy area near Juniata.

Through Wells and Novesta townships the bowldery belt probably marks the line of its flow at the lower level. The part of the belt which comes from the southeast in Novesta Township is in all probability due to the scour of the stream without the aid of the ice front in contributing bowlders. The bowlder belt heads near Novesta, and the two arms of the long swamp of the south branch of Cass River end there. The altitude is now 775 to 780 feet and was originally 80 or 85 feet lower.

The flow of the East Dayton spillway was certainly very short lived as compared with the Imlay outlet river. The river was probably temporary and existed only during a brief halt in a relatively rapid retreat of the ice front in the transition from Lake Maumee to Lake Arkona. The spillway appears to head on the till plain of Sanilac County and is not known to be related to any beach.

NORTH BRANCH TRANSVERSE CHANNEL.

From the extreme northeast corner of Burnside Township, Lapeer County, a well-developed channel, known as the North Branch transverse channel, runs southwest and west to the Imlay channel, a mile above North Branch. It is a swampy depression of varying width down to a point about 5 miles east of North Branch, beyond which it is floored with gravel. The gravel-floored part is one-third to one-half mile wide and the bordering land rises 20 to 40 feet, but not steeply.

LAMOTTE CHANNEL.

The channel associated with the Lamotte esker is closely related to the North Branch transverse channel. From the northeast corner of Lapeer County the Lamotte swamp runs directly north along the south branch of Cass River, expanding within 3 miles to a width of 2 miles. For 6 miles farther north it contains the broken chain of the Lamotte esker. Two miles still farther north it divides into two branches of irregular width, both of

which bear northwest to a point near Novesta, where they meet the east end of the bowldery belt that marks the East Dayton spillway.

The Lamotte channel was made originally by a southward-flowing subglacial stream or one flowing in an ice-walled canyon in the thin mass of dead ice which appears to have covered the till plain of Sanilac County at that time. The ice front then rested about on the Deanville and Mayville moraines, and the part of the channel which lay outside of the ice front (now constituting the North Branch transverse channel) became an important line of glacial drainage tributary to the Imlay channel, and the stream that flowed in it appears to have deposited the gravels in its western part. Later, during the life of the East Dayton spillway, the northern part of the Lamotte channel was occupied by a stream flowing in the opposite direction (northward). This stream collected the thin sheet of water coming over the flat till plain from the east and guided it to the ice front northwest of Novesta and thence southwest through the East Dayton spillway to Lake Saginaw. If the East Dayton spillway served as an outlet for Lake Maumee its service must have been short, for it does not extend east of East Dayton, unless indeed its continuation there was obliterated by a readvance of the ice to the Juniata moraine. If it was not obliterated by readvancing ice this spillway must have received its waters from a thin sheet of water which came over the divide at the east and south but which did not last long enough to cut the channel back that far.

Thus the Lamotte channel was originally the headward, ice-bound part of the stream that flowed westward through the North Branch transverse channel. After the ice disappeared its northern part near Novesta probably became a headward northwestward-flowing tributary to the East Dayton spillway and served for a brief time as the outlet of a late stage of glacial Lake Maumee.

MORAINES OF THE HURON-ERIE SLOPE IN MICHIGAN.

By FRANK B. TAYLOR.

GENERAL FEATURES.

The moraines of the Huron-Erie slope in Michigan lie in a belt 20 to 30 miles wide extending southwest from Port Huron and Imlay along the southeast border of Michigan for a little more than 100 miles. Imlay is on the forty-third parallel of latitude and Port Huron is 5 miles south of it. Into the north end of this district the West Branch-Gladwin group of moraines emerges after having passed through the tangle of the interlobate area. Seven or eight individuals are recognizable, but only the first or earliest and one or two later fragments are land-laid. All the rest are water-laid and faint and are traceable with certainty for only short distances.

The Portland moraine which runs past Hadley turns southeast in the central part of Lapeer County and appears to find a continuation in the Defiance moraine, which runs southeast from Belle River, a few miles west of Imlay. This correlation is not certain and may require revision later but is the best now available. Thus the Defiance moraine appears to stand as the equivalent of the earliest part of the West Branch morainic system in the interlobate and Huron-Erie districts, but not in the central part of the Saginaw basin, where there are three earlier ridges. It is considerably stronger than the average individual of the deployed group in the Saginaw Valley. The same is true of most of the moraines south and southwest of the Defiance in Ohio and Indiana, so that in its general characters it seems more nearly related to them than to the deployed group. Still, the connection in Lapeer County seems fairly clear, and the Defiance moraine is therefore treated as being equivalent to the earliest part of the West Branch morainic system on the Huron-Erie slope. It seems to be of the order of a substage, whereas the fainter set following immediately after it is of lesser rank. The relation seems to be the same as that obtaining in the Fort Wayne moraine, where the strong front ridge is followed by several weaker ones.

DISTRIBUTION OF MORAINES.

DEFIANCE MORAINE IN SOUTHEASTERN MICHIGAN.

By FRANK LEVERETT.

COURSE AND DISTRIBUTION.

In Monograph XLI a description of the Defiance moraine as far north as the Ohio-Michigan line was given and its relations to Lake Maumee were discussed. It lies in the midst of the Maumee basin in northwestern Ohio and marks the position of the ice border during a considerable part of the life of the first Lake Maumee. The Michigan portion lies outside the limits of Lake Maumee except in Lenawee County from the vicinity of Adrian southward. The recession of the ice from this moraine permitted the lake to extend northward to the Imlay outlet. That this moraine may mark a readvance of the ice border at least along part of its course is suggested (1) by the strength of the Maumee beach just outside the moraine near Findlay, Ohio, which seems to demand a greater expanse of water than would lie in the narrow space between the moraine and the beach; and (2) by the somewhat greater breadth of the lobe in the Maumee basin as compared with that which formed the weak ridges between this moraine and the Fort Wayne. (See pp. 168-170.) This broadening of the lobe brings the moraine very close to the neighboring outlying ridges on the periphery of the basin, though in the axis it falls some distance short.

The Defiance moraine runs northeastward from the Ohio-Michigan line past Adrian, Tecumseh, Saline, Ypsilanti, Northville, and Amy to Clinton River a few miles east of Pontiac. It has a double crest and is more or less distinctly separated into two members, with intervening till plain and gravel plain, for a few miles in

the vicinity of Ann Arbor. This has led to the introduction of the terms "outer Defiance ridge" and "inner Defiance ridge" in the revised edition of the Ann Arbor folio and in the Detroit folio. The outer Defiance ridge is the "middle" moraine of the first edition of the Ann Arbor folio and the "Northville" moraine of the report on Wayne County, Mich., by W. H. Sherzer, published by the Michigan Geological Survey.

North from Clinton River the Defiance moraine is in places banked against an earlier moraine and in places separated from it by a narrow glacial drainage channel. It can be traced as far as Belle River a few miles west of Imlay, beyond which point its continuation is uncertain. Probably, however, it constitutes the outer part of a morainic system that runs northwestward from Imlay into a reentrant angle between the Huron-Erie and the Saginaw lobes north of Lapeer. If it does this, it is probably represented in the Saginaw basin by the Portland moraine and perhaps by one or two other members of the system of slender moraines between the Charlotte morainic system and the Port Huron morainic system.

TOPOGRAPHY.

The moraine rises from about 800 feet above sea level in the vicinity of the Ohio-Michigan State line to 1,000 feet on the highest points in northeastern Oakland, northwestern Macomb, and eastern Lapeer counties. In all these counties portions of it rise but little above 900 feet, so that the general rise in the Michigan part is but little more than 100 feet.

Near the State line of Ohio and Michigan the moraine changes from a very smooth water-laid ridge to a gently undulating land-laid moraine. In places two or more ridges are recognizable, but as a rule the crest line is single. At Adrian two ridges of about equal strength are present, but between Adrian and Ypsilanti wherever two ridges are present the outer or western is much stronger than the inner or eastern. Portions of the inner ridge in the vicinity of Ypsilanti are below the level of Lake Maumee, and in southern Washtenaw County its crest almost coincides with the highest beach of Lake Maumee. From the State line northeastward to Clinton River the surface of the ridge is gently undulating and is characterized in places by numerous basins, especially in the Ann Arbor quadrangle west of Ypsilanti. From Clinton River northward to southern Lapeer County large kames 75 to 100 feet or more in height are distributed along the moraine and stand in striking contrast with the gently undulating portion farther south.

STRUCTURE OF THE DRIFT.

Along much of its course the moraine is clayey, though many of its small knolls are composed in part of sand or gravel, and gravel is present in large amounts in the kames north of Clinton River. The moraine is in places coated with a sandy deposit due probably to flooded conditions of the country immediately outside the moraine, for the ice was banked against a slope which gathered waters from higher land to the west as well as from the melting of the ice. These sandy deposits are conspicuous in the vicinity of Saline River in southern Washtenaw County and northeastward from there to Ypsilanti. There is also considerable sand in the vicinity of the State line on both the Ohio and the Michigan sides.

OUTER BORDER DRAINAGE.

The flooded condition on the outer border of the moraine just noted is conspicuous only south of the latitude of Ypsilanti. Northward from that city as far as Clinton River there is a channel which appears to have had a southwestward-flowing current of water that was strong enough in parts of its course to carry gravel of medium coarseness. In other parts pools existed, and these are coated only with sand or fine material. It is probable that at the time of the development of this moraine a small lake occupied a basin around Lapeer (see pp. 273, 274); its correlation with this morainic system depends on the course of the Defiance moraine through Lapeer County.

BIRMINGHAM MORAINE.

By FRANK B. TAYLOR.

COURSE AND DISTRIBUTION.

The Birmingham moraine appears to correspond to the Lyons moraine of the Saginaw lobe. It is strongly developed from north-central Lapeer County down to the north bank of Belle River, a mile north and west of Imlay, but from Belle River to Romeo it is weak. Just north of Belle River and 11/2 miles west of Imlay morainic masses of considerable height, apparently belonging to this moraine, appear to have pushed westward and closed the Lum channel.

In the stretch of 2 or 3 miles west and southwest from Imlay there is nothing that seems distinctly morainic. The surface is smooth with only the faintest suggestion of undulation or ridging, but it is rather plentifully covered with bowlders. North and south through the central part of this small plain area a belt nearly a mile wide, bearing almost no bowlders, is smoother and flatter than the ground on either side of it. This strip is believed to mark the interval between the Defiance and Birmingham moraines, the faintly undulating bowldery belt west of it corresponding to the Defiance moraine and the narrow strip east of it to the Birmingham moraine.

The interval of 5 or 6 miles between Mill Creek northwest of Imlay and the south edge of this bowldery plain is the only place where clear separation between the two moraines is lacking. At the south edge of this plain a small tributary of Belle River flows eastward, crossing the two moraines in sec. 36, Attica Township, and secs. 31 and 32, Imlay Township.

In secs. 36 and 31 a small but well-defined glacial river bed, the Almont channel, comes from the northwest out of the flat area in the west-central part of Attica Township. This drainage line is small but is remarkable for the persistence with which it keeps its way along the west side of the belt of low bowldery knolls and gravel

deposits which represent the Birmingham moraine from Imlay to Romeo. It is sinuous, especially between the southeast corner of Attica Township and Almont, but it is not broken or interrupted. It is well developed at the western edge of Almont and near the county line 4 miles south.

It seems necessary to mention this channel in advance of the discussion of the glacial drainage of this district, because it is this drainage line more than anything else that makes certain the continuity of the faint moraine between Imlay and Romeo. In the interval between the southeast corner of Attica Township and Romeo—a distance of 12 or 13 miles along the channel—there are not less than 10 gaps in the low moraine to the east through which this stream would certainly have flowed to the lower ground of the Imlay channel and Clinton River if they had not been closed by the solid ice that was then resting on the moraine. It may be observed also that a considerable part of the Birmingham moraine in this interval of weak development lies below or east of the highest or first Maumee beach. From these considerations it is clear that however weak and slender the Birmingham moraine appears to be in the interval between Imlay and Romeo, it is nevertheless present and may be depended on in the correlation of moraines, ice movements, and glacial drainage in this vicinity. In this interval of faint development there is only one prominent knoll to mark its course, and this lies obliquely, extending 11/2 miles northeast from Almont. The reason for the faintness of the Birmingham moraine in this interval will be discussed to better advantage in connection with the glacial drainage (pp. 283-284).

At Romeo the 400 or 500 yard Almont channel passes into the mile-wide Rochester channel west or in front of the strong, high morainic ridge which begins at Romeo and extends south-south westward, past Rochester and Birmingham, opening out at the latter place upon the lake plain below the highest beach of Lake Maumee.

The Birmingham moraine from Romeo to a point about 3 miles northeast of Rochester is a high, relatively narrow ridge of bowlder clay and is in fact one of the most sharply developed and clearly defined terminal moraines in this region.[1] Beyond this point the strongly developed ridge ends and is replaced by a small till plain, and where the moraine reappears south of the Clinton River it is relatively low and smooth. South of sec. 22, Avon Township, Oakland County, to Birmingham its crest steadily falls, gradually losing its expression as a land-laid moraine. It continues, however, 6 or 7 miles southwest from Birmingham as a low, smooth swell which controls the course of Rouge River. At Birmingham it merges with the north end of a much broader low ridge, probably interlobate in character, which runs southeastward directly down the slope to Detroit and thence southeastward nearly to the shore of Lake Erie at Leamington, Ontario. The continuation of its Lake Erie correlative in Wayne and Monroe counties as a water-laid moraine[2] and bowldery strip will be discussed later (pp. 287-289).

TOPOGRAPHY.

ALTITUDE AND RELIEF.

At Imlay the Birmingham moraine, or rather the bowldery strip which represents its faint development, has an altitude of 860 to 880 feet. Thence southward to Almont it declines at about the same rate as the highest beach of Lake Maumee, and in the south part of Almont it has an altitude of about 845 feet. Only the large knoll northeast of the village rises much above the beach, attaining an altitude of 865 to 870 feet. From Almont south to Clinton River north of Romeo the moraine is very low, being in places slightly above the level of the beach and in places slightly below it. The altitude of the beach at Romeo is about 830 feet.

At Romeo the moraine suddenly becomes strongly developed, though not more than 11/2 miles wide, and continues so to a point 3 miles northeast of Rochester, its crest rising in several places above 900 feet and having an average elevation of about 870 feet. A till plain of about a square mile with an altitude of 760 to 780 feet there takes the place of the moraine. South of Rochester in a small area in sec. 22, Avon Township, the crest rises to an altitude a little above 860 feet; beyond, it declines steadily at the rate of about 10 feet to the mile to an altitude of 780 feet at Birmingham.

From Imlay to Romeo the Birmingham moraine has extremely slight relief, few of its knolls rising more than 10 or 15 feet above the adjacent ground. At Romeo and southward it has a steep slope on both its sides and rises 60 to 100 feet above its base. South of Rochester it has a relief of 60 or 70 feet, but declines rapidly toward Birmingham.

CHARACTER.

From Imlay to Romeo the moraine generally consists of low bowldery knolls, with some small kames and gravel ridges. For much of the distance the crest is only a little above the highest beach of Lake Maumee, and toward Romeo it at some places passes below the beach level, the beach appearing only on small islands.

From Romeo to Rochester the strong moraine has a swell and sag topography, with some basins where its slopes have not been subsequently modified. Its eastern slope, however, was heavily undercut after it was made and has since been deeply gashed with ravines. For 3 or 4 miles south of Rochester the ridge has a faint swell and sag expression, but within a short distance farther south it becomes smooth and devoid of notable surface features.

[1] See Rochester topographic sheet of the U. S. Geol. Survey.

[2] In 1913 Leverett and Sherzer found evidence of the continuation of the moraine in water-laid form along the east side of Rouge River to the Wayne County line. There are slight undulations on its southeastern or inner slope, and the relief on that side is in places easily perceptible to the eye, being 15 feet or more in half a mile.

STRUCTURE OF THE DRIFT.

From Imlay to Romeo the moraine is generally bowldery on the surface, but is composed largely of clay beneath, though it comprises several gravel deposits in the form of kames, the most notable ones being in secs. 33 and 34, Imlay Township, and sec. 35, Almont Township, and several smaller ones between Almont and Romeo. The strong ridge back of Romeo is composed mainly of stony clay but has kames and much sandy outwash along its west front in the northern part of Washington Township. Southward from Rochester the ridge is composed more generally of clay.

GLACIAL DRAINAGE.

As nearly all the moraines of the Huron-Erie slope in Michigan are water-laid, there is relatively little ice-border drainage to discuss. Mr. Leverett has described that associated with the Defiance moraine farther south (p. 281), and the writer has discussed the relation of the Imlay outlet to the moraines that border upon it (p. 277). What remains is mainly drainage associated with the Birmingham moraine.

ALMONT CHANNEL.

As Mr. Leverett has pointed out, the Defiance moraine pressed against the earlier deposits in the vicinity of Amy, 4 or 5 miles east of Pontiac, and interfered with the southward drainage from the interlobate angle in Lapeer County. This interference led to the development of a line of glacial drainage that went northward through eastern Dryden Township, Lapeer County, turning northwestward a mile northeast of Dryden. The channel is very plain in southern Attica Township, where two or three branches follow narrow courses between high morainic knolls.

A small, narrow channel, known as the Almont channel, opens out of the eastern branch in a nearly reverse direction or a little south of east. It is commonly not over 400 or 500 feet wide and to Almont is rather crooked. Its course and character and relations as far as Romeo have already been described (p. 281). West of Romeo it passes into the broad Rochester channel, which lies in front of the strongly developed part of the Birmingham moraine, but for 4 or 5 miles it keeps in its narrow bed, with the outwash rising 40 to 50 feet above it; finally it loses its identity in a swamp in the southwest part of Washington Township, Macomb County.

At its head in sec. 26, Attica Township, Lapeer County, the altitude of the Almont channel is 880 or 890 feet, at Almont about 830 feet, west of Romeo about 810 feet, and in southwestern Washington Township 800 feet. Its length is about 20 miles and its descent 80 to 90 feet. Allowing for subsequent tilting of the land, its original descent was 60 to 70 feet, for the river flowed toward the south.

ROCHESTER CHANNEL.

A valley about a mile wide begins about 2 miles west of Romeo and extends southwest along the west or front side of the strongly developed part of the Birmingham moraine to Birmingham. A mile or two southwest of the latter place it opens out onto the eastward slope of the old lake bottom below the highest beach of Lake Maumee. Throughout its 20 miles of length it maintains a constant relation to the Birmingham moraine. Its character and relations strongly suggest that it is a fragment of a large glacial drainage channel, and it is here termed the Rochester channel.

Its connections and relations to other drainage, however, are obscure, its greatest peculiarity being its abrupt termination at its north end, where it is 11/2 miles wide and where, except for its narrow entrance, it is surrounded on the east, west, and north by morainic deposits that rise 100 feet or more above it. The sandy and gravelly deposits on its floor are not smoothly laid, like the floors of most drainage channels, but show considerable irregularity. For 4 or 5 miles from the north end it is filled with sandy outwash from the Birmingham moraine to a level of 840 to 860 feet, which is considerably higher than its general level farther south. Between Rochester and Birmingham it is again filled with a wide flat deposit of outwash up to 810 to 815 feet. Near its north end it has swampy areas, which lie below 800 feet and which seem to be original depressions not scoured out by a river. Nevertheless, it seems much like the channel of a great river, and it is tentatively suggested as the possible correlative of the Lum channel 20 miles farther north.

Certain facts strongly suggest this possibility. In the first place, both the Rochester and the Lum channels lie close against the front of the Birmingham moraine, and it seems clear that if this moraine had drawn back a little from its present position between Romeo and Lum it would have permitted a continuous open passage between the two places.

In the second place the weak and greatly modified part of the Birmingham moraine lies just in the interval between the north end of the Rochester channel and the south end of the Lum channel, as might be expected if the channel had been closed in this interval by a readvance of the ice. The facts are so simple that it seems impossible to doubt the reality of this event.

But if these channels are related in this way the altitudes of their floors are such that it would be necessary to suppose that the land around the Lum channel stood somewhat lower with reference to the Fort Wayne outlet than it did later at the time of the Imlay outlet, and hence that after the Lum channel was closed and before the Imlay was opened there was a slight elevation of that region. That such an elevation took place is not inconsistent with the later history of this district.

Regarding the Rochester-Lum channel as a former outlet of Lake Maumee, it may be noted that its head was near Birmingham and that if allowance is made for the later sandy outwash that covers the channel floor between Rochester and Birmingham the head appears not to have been measurably affected by this early uplift,

for the channel still stands in normal relations to the highest beach of Lake Maumee at Birmingham. It appears to follow that the uplift which elevated the Lum section before the opening of the Imlay channel did not affect the land at Birmingham; nor, so far as indicated by the highest beach of Lake Maumee, did it affect any of the lands bordering on this lake farther south.

When compared with other parts of the shore the inner slope of the moraine between Rochester and Romeo appears to be steepened more than would be expected from wave action, and from this it is inferred that as the ice front drew back from the Birmingham moraine the waters of Lake Maumee rushed northward through a narrow passage between the ice and the inner side of the moraine and cut away the base of the latter. At Romeo the middle beach of Lake Maumee runs along the crest of a small, narrow morainic ridge—apparently the last stand of the ice during the building of the Birmingham moraine. Between this and the high moraine there is a trough one-fourth mile wide which seems to have been scoured out when the ice stood at the position of the middle beach. These two features are distinctly developed in the south part of the village of Romeo. Later, when the ice had withdrawn eastward the waves of the lake at the level of the first or highest beach made a shore line along the base of the hill a few feet above this channel floor. The inner slope south of Rochester is not steepened in this way.

WATER-LAID MORAINES AND BOWLDERY STRIPS.

The water-laid moraines and bowldery strips are less definite than the land-laid ones, and their correlations are more or less uncertain. It is thought best, however, to describe briefly such of their features as seem to throw light on the recession of the ice sheet from the southeastern part of Michigan. There is more room for difference of opinion here than there is in regard to the well-defined glacial features, and much that is here presented must be regarded as tentative.

DETROIT INTERLOBATE MORAINE.

The broad, smooth ridge running directly down the slope from Birmingham to Detroit (p. 292; also fig. 13, p. 485) is not to be regarded as the normal continuation of the Birmingham moraine, for such an assumption would involve a violation of the fundamental principles of the adjustment of a semiplastic ice mass to topography and of the law governing liquid or semiliquid bodies moving on the line of least resistance under the force of gravity.

The Birmingham moraine appears to continue southwestward beyond Birmingham as a bowldery strip with the same normal altitude relation that it has between Romeo and Birmingham; gradually declining in that direction. The broad, low ridge between Birmingham and Detroit runs directly down the slope, almost at right angles to the normal trend of the Birmingham moraine. This seems to suggest that the Detroit ridge is not a terminal moraine in the ordinary sense but is an interlobate moraine marking the line of contact between the Lake Huron ice lobe coming from the northeast and an extension of the main Lake Erie lobe to the north and northwest.

This inference is strongly supported by glacial striæ, which were found by Sherzer[1] to run north-northwest, in the Sibley limestone quarries north of Trenton, and by a number of other northwest-pointing striæ at Stony Point and Monroe (p. 290). It is also supported by the transportation of bowlders from Lake Erie northwestward to the vicinity of Ypsilanti and Ann Arbor. It seems probable, therefore, that the Detroit ridge is a subglacial, partly water-laid, interlobate moraine; that is to say, that it was formed along the line of contact between the Huron and Erie ice lobes, but mainly under the ice and below the then existing level of the lake. It follows that southwest of Birmingham the ice front was probably standing on or not far from the normal line of continuation of the Birmingham moraine.

IMLAY MORAINE.[2]

The northern part of the Imlay moraine has been briefly noted as a probable partial correlative of the Fowler moraine (p. 241). Only one short, narrow piece of the Imlay moraine forming the east bank of the channel east of Imlay rises above the level of the first beach of Lake Maumee. It is a stony till ridge about a quarter of a mile in width and 870 feet in altitude. From this place the moraine is developed northward along the east side of the Imlay outlet and also runs south-southeast close along the east side of the Imlay channel to a point east of Almont, and then in fading form, marked mainly by a bowlder belt, it continues southward along the east side of Clinton River nearly to Romeo. A mile or two northeast of Romeo it appears to be represented by a thin, flat sheet of stony till, overlying gravel beds. This is the farthest point south to which it has been continuously traced. South of the small till ridge opposite Imlay the moraine is all water-laid and passes southward deeper and deeper under the level of the first Maumee beach.

East of Romeo and farther south a strongly marked bowldery belt covers much of the vertical interval between the Maumee and Whittlesey beaches. The bowlders probably represent the Imlay moraine in large part but scarcely suffice to fix its course definitely. Farther south a single group of distinctly morainic knolls that seem likely to belong to this moraine is found in Troy Township, Oakland County, 3 or 4 miles east and northeast of Birmingham. These knolls, which are composed of stony till and are 5 to 12 feet high, are the more noticeable because they stand on a slope which, except for beach ridges, is smooth.

GOODLAND MORAINE.

On the forty-third parallel the narrow, smooth ridge of the Goodland moraine lies a mile east of the Imlay moraine, from which it is separated by a swamp. Half a mile east of the Good-land moraine another swamp stretches away to the east, north, and south. The moraine bends gradually southeast and runs past Smith station for

about a mile beyond the line of Armada Township, Macomb County. Throughout the whole distance it is a low, smooth ridge, apparently water-laid, rising 10 to 25 feet above the adjacent till plains, and a quarter of a mile to a mile wide. The Goodland moraine was not certainly traced farther, but it seems probable that it turns south in sec. 3, Armada Township, and causes the southward bulge in the Whittlesey beach 2 miles southwest of Armada. Just below the Whittlesey beach a bowldery area bearing some low stony knolls probably belongs to the Goodland moraine, but farther south nothing was seen that could be certainly identified with it. From a mile south of Belle River to its end in Armada Township it is surmounted with gravelly beach bars of Lake Maumee.

[1]Sherzer, W.H.; Ice work in southeastern Michigan: Jour. Geology, vol. 10, pp. 194-216.

[2]This moraine and the Goodland moraine, regarded as one individual, were formerly described as the Toledo moraine (Bull. Geol. Soc. America, vol. 8, 1897, p. 39).

BERVILLE MORAINE.

Another slender water-laid moraine, called the Berville has not been certainly identified with any of the moraines farther north. It is best developed between Belle River and a point in sec. 7, Richmond Township, Macomb County. It is of about the same strength and character as the Goodland moraine, rising 10 to 25 feet above the adjacent lands, and like it is surmounted by bars of Lake Maumee. Its course beyond sec. 7, Richmond Township, is not clear, but, as the ice front generally fitted itself to topography and as moraines in a country as smooth as this tend to be nearly parallel, it is thought that it turns south or perhaps a little west of south. A mile and a half southeast of Armada a very bowldery tract below the level of the Whittlesey beach lies in the line of the moraine if the latter turns southward, but neither this nor anything else in that direction was certainly identified with it.

Northwestward from the hamlet of Belle River the Berville moraine is continued up to the great transverse stony ridge which runs southwest through Mussey Township, and it probably includes some knolls that stand a mile farther west. Its identity farther north was not made out. Its relation to the Goodland and Imlay moraines suggests that it may belong to the Otisville moraine, which runs southeast from Clifford.

MOUNT CLEMENS MORAINE.

A faint water-laid moraine, the Mount Clemens, has been identified as far north as northwestern St. Clair County. It runs southeast through secs. 14, 13, and 24, Mussey Township, and 19, 30, 31, and 32; Emmett Township, and thence directly southeast to a point about 2 miles north of Memphis. In secs. 15 and 16, Riley Township, a transverse kame or short esker marks the place of this ridge, which is there very faint but which appears to turn south past Memphis and becomes quite prominent just west of the Whittlesey beach about halfway between Memphis and Richmond, where it has almost the relief and expression of a land-laid moraine.

Southwest of Richmond the slope below the Whittlesey beach is rather stony; two or three miles to the southwest low stony knolls begin and a broad ridge runs directly south past New Haven, Chesterfield, and Mount Clemens, and on southwest to the south line of Macomb County north of Detroit. Near the county line it broadens and fades out as a perceptible ridge, but in all probability continues southward into the city of Detroit and merges into the Detroit inter-lobate moraine.

From a point 3 or 4 miles north of New Haven to a point nearly 10 miles southwest of Mount Clemens the moraine is well developed. It is this ridge which produces the remarkable concentration of the numerous headward branches of Clinton River into one trunk stream at Mount Clemens. There are no other gaps in the moraine where streams could pass through. For a moraine deposited in water nearly 200 feet deep it is remarkably strong and definite in its development.[1]

EMMETT MORAINE.

The Emmett moraine, so far as yet identified, has its northern end in northwestern St. Clair County, in sec. 12, Mussey Township, and runs southeast, passing a mile west of Emmett. Near Emmett it is fairly strong, but elsewhere it is very weak. It was not definitely recognized farther southeast, but it probably coincides with the Whittlesey beach toward the southeast a mile north of Lamb. Beyond this it is indicated only by an ill-defined stony belt. It is probably this moraine that gives Belle River its sharp turn just west of Columbus. From Columbus to a point west of Casco it is broken by a gap of about 4 miles, but it is probably continued near New Baltimore by a low ridge of bowldery clay. A mile and a half west of New Baltimore it ends as though cut away by wave action, rising 30 to 35 feet above the plain. Although it does not appear farther on as a ridge, it probably deflects the lower part of Salt Creek to a little west of south.

[1]In a former publication (Bull. Geol. Soc. America, vol. 8, 1897, p. 39) the writer called this same ridge the Detroit moraine. It was not seen until later that the broad ridge which passes through Detroit is interlobate in character and extends directly up the slope to Birmingham.

The United States Lake Survey chart of Lake St. Clair shows some interesting features which are thought to have connection with this moraine. Just outside the head of Detroit River the villages of Grossepoint and Claireview are situated on a well-defined ridge of bowldery till, evidently a terminal moraine, about a mile wide and 2 or 3 miles long. The shore along its front is thickly strewn with bowlders. At one place on its western edge the ridge rises to an altitude of 620 feet, or about 45 feet above Lake St. Clair. Northward to Milk River Point this ridge dies down and disappears, but it is shown by the chart of Lake St. Clair to be continued as a low, submerged ridge running north for 5 or 6 miles, and then to reappear as stony till in the land that projects like

a delta of Clinton River below Mount Clemens. All of these features are precisely in line with the ridge back of New Baltimore, and may reasonably be regarded tentatively as parts of the Emmett moraine. The small bowldery knoll at Windmill Point, in the east part of Detroit, probably also belongs to this moraine. Beyond this, however, nothing that could be identified with it was observed. In all probability it merges into the Detroit interlobate moraine on the Canadian side of Detroit River.

ADAIR MORAINE.

Northwest of Avoca the Yale moraine is a strong and apparently land-laid deposit, but south of this latitude it has not been definitely recognized. If it continues its trend from the region of strong development it might be expected to run southeast close to Pine River—perhaps on the east side—to the western part of Kimball Township and to curve thence slightly west of south in conformity with the other moraines. Its continuation may be found in a bowlder belt, known as the Adair moraine, running a little east of north from a point near the shore of Lake St. Clair about a mile northeast of Fair Haven and passing a little east of Adair to the bank of Pine River in sec. 16, St. Clair Township. In some places it is a low ridge with a relief of a few feet, but in most places its relief is scarcely perceptible. Its course is marked nearly everywhere by a moderate number of bowlders and by bowlder clay bordered on both sides, but particularly on the east, by a formation that is without bowlders and is largely composed of lake clay. If the lake clays along the south part of the belt were removed it seems quite probable that the bowlder belt would stand out as a perceptible ridge.

The United States Lake Survey chart of Lake St. Clair shows nothing in the bed of the lake that could be correlated with this moraine, but an exposure of bowldery till and a low knoll at Stony Point on the south side of Lake St. Clair, 20 miles east of the head of Detroit River, may belong to it.

TRANSVERSE RIDGES.

Two of the transverse ridges that run southwest across the forty-third parallel in southwestern Mussey Township, St. Clair County (p. 266), appear to fade away in a swamp at the county line in secs. 30 and 31. They may, however, be continued in a remarkably bowldery tract that appears where Belle River breaks through the Imlay moraine in sec. 34; Imlay Township. Eskers and ridges such as these are liable to be slightly displaced in passing from one moraine to another. This bowldery tract is only a little north of the direct trend of the ridges in Mussey Township, and it seems probable that it is related to these ridges, which also carry large numbers of bowlders.

BOWLDER BELTS AND SANDY PLAINS OF MONROE AND WAYNE COUNTIES.

Except the low ridge extending 6 or 7 miles southwest from Birmingham, no terminal moraines have been made out with certainty southwest from the Detroit interlobate moraine, Sherzer[1] has found three bowldery belts which he regards tentatively as representing the course of the ice border. These belts are partly concealed and in this way are broken into several detached fragments by the heavy sand belts which cross the region on rather irregular lines. Sherzer's Rawsonville bowlder belt enters Wayne County north of Livonia and runs southwest, passing 2 miles west of Livonia, 2 miles east of Plymouth, and 2 miles east of Denton, and comes down to Huron River at Bellville. It turns wrest up the river and after passing Rawsonville turns toward the southwest but has not yet been traced more than 3 or 4 miles into Washtenaw County. The course and topographic relations of this belt suggest that it is in some sense a continuation of the Birmingham moraine.

[1]Sherzer, W. H., Geological report of Wayne County, Michigan Geol. and Biol. Survey, 1911, with large colored map showing surface, features; Geological report of Monroe County, 1900, map; Detroit folio, Geol. Atlas U. S., U. S. Geol. Survey (in preparation). See also Leverett, Frank, Surface geology and agricultural conditions in the southern peninsula of Michigan, Michigan Geol. and Biol. Survey, 1912, map.

Sherzer's Scofield bowlder belt enters Wayne County northeast of Livonia, passes a mile east of Livonia and Wayne, and crosses Huron River north of Waltz station. Here it turns southwest and passes out of Monroe County west of Ottawa Lake. From the north line of Wayne County this belt descends about 60 feet to Huron River, showing a much greater variation in altitude than is found in any beach in this area. In its course southwest from Huron River it passes Scofield and Maybee in Monroe County and is buried under the heavy sand belt a mile southeast of Ida. According to Sherzer, its presumed continuation emerges from under the sand belt in sec. 28, Summerfield Township, and winds across the southeast corner of Lenawee County into Ohio. On this course it rises from about 625 feet at Huron River to over 700 feet near the west line of Monroe County. This belt may continue to Sylvania, Ohio, and be represented by a low till ridge which runs southwest from that place and controls drainage.

The part of this belt north of Huron River was observed by the writer some years ago and was regarded as a southward continuation of a moraine then called the Toledo moraine.[1]

A third belt, called by Sherzer the Grosse Isle bowlder belt, runs along the shore of Lake Erie back of the marshes. The part between Monroe and the mouth of Detroit River is regarded by Sherzer as a continuation of a moraine that crosses Grosse Isle. Its position in this part may mark a halting place of the margin of the Lake Erie lobe, but its presumed continuation runs southwest from Monroe, rising more than 100 feet to a point a few miles beyond the Ohio-Michigan State line. Such a course seems unnatural for a marginal moraine or for any equivalent of such a moraine of either the Huron or the Erie ice lobes. The medial axis of the Erie lobe at the time of the Defiance moraine passed about through

Toledo, and the Grosse Isle bowlder belt passes only 12 miles northwest of Toledo in a course nearly parallel with the axis. These discrepancies suggest either that this bowlder belt is not the equivalent of a terminal moraine, or else that the parts separated by the heavy sand belt have not been rightly connected.

These bowlder belts show certain characters and relations that led Mr. Leverett and the writer to regard them at first as possible shore lines. The bowlders lie on till and in many places in front of a low bluff or elevation, from the edge of which a more or less extensive and irregular area of fine sand extends westward. Such an arrangement suggests a sandy beach with a bowlder pavement before it. But this combination of features is not everywhere present, and the wide vertical variation of the principal belts seems to preclude the idea of their being shore lines, especially in this area, where all the clearly identified beaches are substantially horizontal.

It is a singular fact that the northern part of each belt is so related to topography that it would seem to be a normal extension from the northeast of some one of the water-laid moraines, while (if the assumed connections are accepted) the southern part of each changes its direction and trend to an upslope course, which is abnormal for a marginal moraine.

In some respects the southern parts of the belts bear a slight resemblance to the transverse ridges of Sanilac County (p. 266). But another possible explanation may be nearer the truths though it has not yet been fully developed and may apply only to the Grosse Isle belt.

[1]Equivalent to the Imlay and Goodland moraines described on pp. 263-285.

At the maximum of the ice extension the Erie and Huron ice lobes were intimately united, forming substantially one solid lobe covering the lowland between the two basins. It is probable, however, that even at the maximum there was a slight depression or crease along the line of junction between them. As the ice sheet retreated in the basins of Lakes Erie and Huron and from the high ground south of Georgian Bay the tendency of the two ice lobes to separate and become distinct bodies became more and more pronounced. In his work on the glacial deposits of the southwestern peninsula of Ontario it has been found by the present writer that, although the highland south of Georgian Bay was completely overtopped during the maximum of the ice, its south-central part was uncovered and became a flat insular area in the ice field, while the two lobes were still intimately united for nearly 200 miles southwest from London. This is called Ontario Island and was at first about 70 or 80 miles long and 10 to 20 miles wide.[1] It seems certain that at this stage of retreat the two lobes, though still united, were differentiated by a depression or crease on the surface of the ice along the line of contact. If any drainage escaped from the area of the island it must have followed this crease southwestward, and if the river thus produced carried sediment it would naturally be deposited where the crease came out to the edge of the lobe.

In Fulton County, Ohio, sand is distributed over a large part of the Defiance moraine. This deposit may have been made by the river just noted, and if there was any tendency to subglacial concentration of drift along its line the result may have been a bowlder belt like those here discussed. The relations observed may be accidental, but the Grosse Isle bowlder belt seems to lead up the slope directly to the sand deposit in Fulton County and its course produced toward the northeast carries it back toward London.[2] The relations of the belts, however, have not been fully worked out and their origin is still problematic.[3]

GROSSE ISLE MORAINE.

On the central part of Grosse Isle the till is thicker and stands slightly higher than at either its northern or southern ends and it is also somewhat more bowldery than the general surface of the region. The same bowldery drift belt extends a few miles southwest from Trenton and seems to find continuation in the bowlder belt described by Sherzer. This part is also marked by well-defined undulations of the surface which are possibly original morainic features, as maintained by Sherzer, but which seem to the writer to be due largely to the scour of early temporary distributaries of Detroit River. (See pp. 487-489.)

Where best developed, southwest of Trenton, the ridges are transverse to the course of the moraine and in the whole area the troughs follow the general slope of the surface, curving around from southwestward courses northwest of Trenton to southeastward courses southwest of Trenton. On the Canadian side a well-defined bowlder belt runs west from the high knoll west of Leamington, passing north of Kingsville and Harrow and trending toward Amherstburg; but it has not been traced across the intervening space. The general relations of the topography to the basin of Lake Erie from which the ice came suggest that this is the normal course of the ice margin from Grosse Isle eastward.

PRE-WISCONSIN TILL.

Till older than that deposited by the Wisconsin ice sheet seems to underlie more or less continuously all of the later or Wisconsin drift in Indiana and the southern peninsula of Michigan. It is generally darker in color than the newer drift, is more stony, and is considerably indurated. It is the hardpan of the well drillers and in places is overlain by an old soil bed or by a bed of decayed ferruginous gravel. In typical occurrences it shows much oxidation along its cracks and joints, the oxidized part appearing as bands of brown next to the cracks and in places extending many feet down into the deposit. All of these characters are not likely to be seen at any one locality, however, for at many places the Wisconsin ice sheet scoured away the old soil and the upper part of the older deposit; and the part remaining maybe only the deeper part and may show little or no

oxidation along its joints. The dark color and the hardness, however, are generally characteristic. The greater number of stones and their more general striation also serve to identify the older till.

[1]The development of Ontario Island is described in a paper by the writer entitled "The moraine systems of southwestern Ontario" (Trans. Canadian Inst., vol. 10, 1913, pp. 1-23).

[2]Sherzer's statement (Geological report on Wayne County, footnote at bottom of p. 82) that this explanation is suggested by the writer for all of the bowlder belts arises from a misunderstanding. The explanation was intended to apply only to the belt which extends southwest from Grosse Isle toward the great sand deposit in Fulton County, Ohio.

[3]An abstract of a paper on the Crease River was given by the writer before the Association of American Geographers at Baltimore in January, 1910.

Along the shore of the "thumb" the older till begins to outcrop about 6 miles north of Lexington. The exposure here is small, but it evidently passes below lake level to a considerable distance. Along the shore 2 miles north of Richmondville it appears in greater thickness and is typical in color, hardness, and content of striated stones, and in the firm manner in which the stones are held, even after the till around them has been largely removed. (See Pl. XII, *A*, *B*.) It is almost as resistant to wave erosion as the shale that outcrops on the same shore but is cut into deeply along its joints. (See Pl. XII, *A*.)

On the shore at Forestville a nearly vertical cliff about 50 feet high consists of old till and a few feet of pebbleless lake clay of the finest texture, known locally as "polish." This lake clay appears to belong with the older till and not with the newer till above.

At Croswell the older till is exposed in the banks and bed of Black River. At the west end of the bridge south of the village it forms a rocklike wall, and a little farther south it is overlain by ferruginous gravels. It may be seen along the banks of Black River for many miles below Croswell. West of Amadore over 30 feet of it is exposed in the west bank of the river.

As already noted (p. 261), it is exposed in a number of places in Tuscola County and appears in most well borings with a thickness of about 100 feet. West of East Dayton its surface is exposed in the base of the hill, where it gives rise to a wet belt or line of springs.

A mile and a half south of Avoca the old till with a distinct old soil at its top is well exposed in the north bank of Mill Creek beneath 28 to 30 feet of the newer till. (See Pl. XIII, *A*.)

STRIÆ.

The greater part of southeastern Michigan is deeply covered with drift and has few exposures of bedrock. On this account, mainly, glacial striæ have been found in very few places. Partly, however, their lack is due to the fact that shales of the softness of those in this region seldom retain striæ, the principal rocks on which they are recorded being limestone and less commonly sandstone.

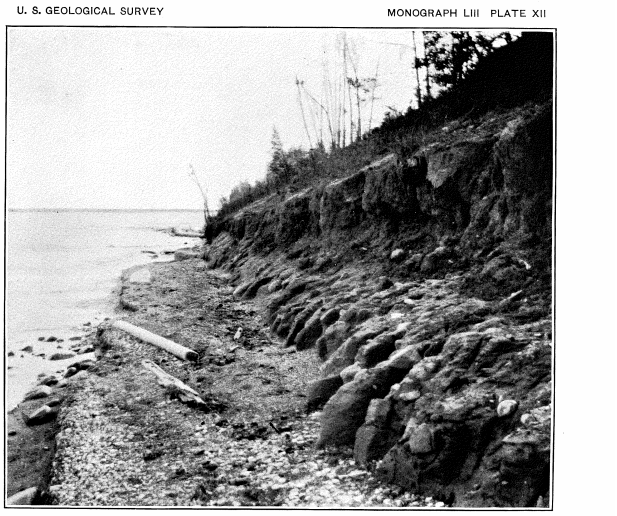
There are finely developed striæ and groovings at the Sibley limestone quarry a mile north of Trenton, and Sherzer reports striæ at several other places in Monroe County.[1] In the Sibley quarry Sherzer distinguishes three sets of striæ and a few broad, shallow troughs which he ascribes to an ice movement earlier than any of those that produced the striæ. In one of the principal troughs he finds the striæ related in such a way as to show in his opinion their relative age or order of making. He concludes that they indicate two ice invasions from the Labrador center. To the writer it seems probable that all the striæ at the Sibley quarry were made by the last ice invasion, but that the troughs are probably older.[2] The rock ledges near Trenton stood as a reef in the axis of flow of the Lake Huron ice lobe during the maximum of the last ice sheet and during a considerable time before and after the maximum, or so long as the ice from the Lake Huron basin pressed southward some distance beyond Trenton. The troughs, however, may not be due wholly to ice work. Still, the position of the Trenton ledge with reference to ice flow from the basin of Lake Huron and of the troughs running back from the struck edge of the ledge is exactly like that on Kellys Island, in Lake Erie, with reference to the ice flow in that basin; and the troughs may therefore have been largely due to the ice work. The principal trough (S. 38° W.) described by Sherzer and the first two sets of striæ (S. 31° W. and S. 68° W.) are evidently due to ice coming from the Lake Huron basin, and the last set (N. 29° W.) is due to ice flowing out of the Lake Erie basin.

The passage of the Erie ice over the Trenton reef could occur only when the Huron ice lobe ended some distance north of Trenton, probably at the Detroit interlobate moraine, which runs south from Birmingham through Detroit and thence southeastward nearly to the shore of Lake Erie at Leamington, Ontario, where it turns toward the east. Only for a relatively brief time would this peculiar relation of the two ice lobes exist, but it would occur both in the advancing and in the receding phase of the invasion. Moreover, it occurred, in all probability, twice in each of the great ice invasions that overspread the basins of Lakes Huron and Erie, for the observed disposition of the pre-Wisconsin drift, especially in the interlobate tracts in central and southeastern Michigan and in the western peninsula of Ontario, indicates the existence of Saginaw, Huron, and Erie ice lobes then in forms substantially identical with those of the last ice sheet. The troughs, lying with their axes in the line of ice movement at the last maximum, in all probability held the same relation to the maxima of each of the earlier invasions, and, in so far as they have been made by ice erosion, they may be in part a product of each of the invasions.

[1]Sherzer, W. H., Geological report on Monroe County, Mich.; Michigan Geol. Survey, vol. 7, pt. 1, 1900, pp. 128-132, map opposite p. 112. The striæ near Trenton are discussed in Sherzer's paper on Ice work in southeastern Michigan: Jour. Geology, vol. 10, 1902, pp. 194-216;

and more fully in his report on the geology of Wayne County: Rept. Michigan Geol. and Biol. Survey, 1911.

[2]In May, 1913, Mr. Leverett visited this quarry and found the order of development of the three sets of striæ to be as follows: (1) S. 31° W., (2) S. 68° W., and (3) N. 29° W.



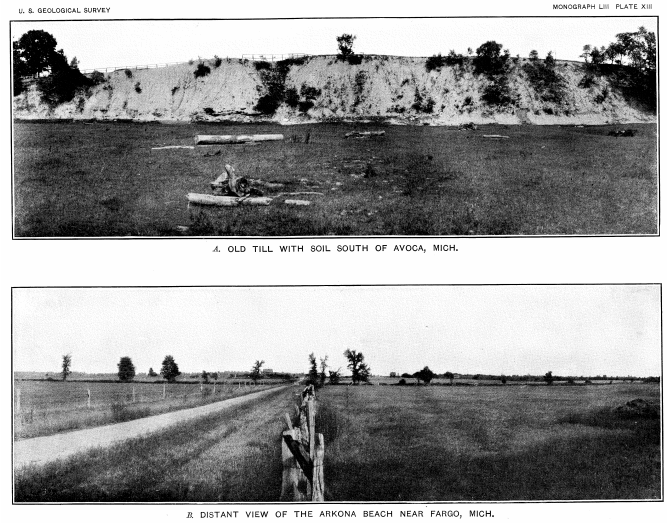
A. GENERAL VIEW.

B. NEARER VIEW SHOWING PEBBLES IN RELIEF.

WAVE EROSION OF PRE-WISCONSIN TILL, RICHMONDVILLE, MICH.

[Plate XII. Wave erosion of pre-Wisconsin till, Richmondville, Mich.: *A*, General view; *B*, Nearer view showing pebbles in relief]

In Monroe County Sherzer reports three sets of striæ at Stony Point and Brest and two sets at each of the following places: Sissung Quarry, Point aux Peaux, Monroe, Maybee, Dundee, and Ottawa Lake. The latest striæ at Sibleys (N. 29° W.) are readily recognized in all these localities, and it is interesting to note that they incline more and more toward the west with increasing distance south from Sibleys, until at Ottawa Lake they run west or slightly south of west. This deflection is distinctly expressive of a lobe spreading northwestward, westward, and southwestward from a central point in the western basin of Lake Erie; and the striæ seem best interpreted as recording the spreading of one lobe at a particular stage and time.



A. OLD TILL WITH SOIL SOUTH OF AVOCA, MICH.

B. DISTANT VIEW OF THE ARKONA BEACH NEAR FARGO, MICH.

[Plate XIII. *A*, Old till with soil south of Avoca, Mich.; *B*, Distant view of the Arkona beach near Fargo, Mich]

The sets of striæ have another significance which is worthy of note. As Sherzer states, three sets at Sibleys are quite distinct from each other, the intermediate courses between each pair of contiguous sets being only sparsely represented. This seems to mean that a given set at this locality was made, not while the ice front was in active retreat, changing its alignment and shifting the courses of the lines of flow to the margin, but while the ice front was stationary or maintaining one position steadfastly. It is therefore concluded that each set of striæ stands for a pause in the retreat of the ice front, and hence corresponds to or is the correlative of a terminal moraine. From this point of view it seems probable that the striæ running N. 29° W. at Sibleys are correlatives of a moraine of the Lake Erie lobe which is itself the correlative or complement of the Birmingham moraine of the Lake Huron lobe and in part also of the Detroit interlobate moraine. Where no notable change of frontal alignment took place between the pauses in the retreat, the direction of the striæ might remain unchanged, and so represent more than one moraine. Such preservation of frontal alignment is generally maintained along the axis of a lobe; and the striæ running N. 29° W. at Sibleys, being nearly on the axis of the small sublobe which reached northwest from the mouth of Detroit River, may represent pauses of the ice front corresponding to all of the slender moraines from the Birmingham to the Mount Clemens.

CORRELATIVES IN OHIO, NEW YORK, AND ONTARIO.

By FRANK B. TAYLOR.

GENERAL CORRELATION.

It seems certain that the group of slender moraines sweeps across the Maumee Valley from the Detroit interlobate moraine to the shores of the glacial lakes in eastern Ohio, Pennsylvania, and western New York. A

number of the slender moraines are known to pass beneath the Maumee shores and they are believed to emerge east of Cleveland, where Mr. Leverett has mapped a number of moraines constituting his escarpment system.[1] Mr. Leverett shows others emerging farther eastward in Pennsylvania and New York.

The later moraines of the same series in Michigan sweep northeastward and northward through Ontario, emerging northwest of London. Thence they run northward and eastward around the upper edge of the highland south of Georgian Bay and, bending in wide curves, return southward on the east side, passing across the eastern end of Lake Erie. The writer has traced parts of all of those in Ontario,[2] and in all these localities the strength and character and general relations of these moraines show a strong resemblance to the system of slender individuals which is so well displayed in the eastern limb of the Saginaw lobe.

[1]Mon. U. S. Geol. Survey, vol. 41, pp. 651-672, Pls. XV and XVIII.

[2]The moraine systems of southwestern Ontario: Trans. Canadian Inst., vol. 10, 1913, pp. 1-23, with map.

DETROIT INTERLOBATE MORAINE IN SOUTHWESTERN ONTARIO.

On account of its intimate bearing upon the relations of the Huron and Erie ice lobes during the time of their shrinkage and separation the following facts are given relating to the moraines in the region east of Detroit River, chiefly in Essex, Kent, and Elgin counties, Ontario. The Detroit interlobate moraine runs southeast in a direct line from Detroit to the high ground a mile or two northwest of Leamington. It carries the Talbot road on its broad crest for a large part of the distance, and from Essex to 2 miles southeast of Cottam it carries also a finely formed gravelly bar of the Grassmere beach. From Leamington its probable continuation runs as a low, flat divide northeast to the county line and then east to Port Alma, where it forms a high bluff on the lake shore. To the east, after an interval of about 12 miles in which it has been cut away by the present lake, it reappears 5 miles southwest of Blenheim in a bluff 80 feet high as a more distinct morainic ridge, with beaches on its crest and flanks. From the lake shore it runs northeast through Blenheim and passes about 2 miles southeast of Ridgetown. A mile or two east of Port Alma small drainage courses, which formerly headed south of the bluff, show clearly the former existence of higher ground in that direction. From the trend of the ridge at both points on the bluff and from the decapitated stream beds it seems certain that part of this higher ground, now cut away by the waves, was at least 1 or 2 miles out from the present shore.

So far as can be judged on present information this ridge is continuous with the Detroit interlobate moraine and is interlobate in character throughout. It seems to have been begun at the time of the Birmingham moraine and probably represents several later subordinate halts of the ice front. If this ridge is interlobate it shows that at the time of its formation the Huron lobe was crowding the Erie lobe to the south and was even pressing slightly over Into the space now occupied by Lake Erie. (See Pl. V, p. 62; also fig. 13, p. 485.) At earlier stages of the ice recession the interlobate line probably extended more directly southwest from Leamington; during the building of the Defiance moraine it probably terminated at the sand deposit in Fulton County, Ohio.

CHAPTER XI.
PORT HURON MORAINIC SYSTEM AND PROBABLE CORRELATIVES.

PORT HURON MORAINIC SYSTEM IN HURON AND SAGINAW BASINS.

By FRANK B. TAYLOR.

GENERAL RELATIONS.

The Port Huron is a complex system of moraines rather than a single individual, but its component ridges are not so prominent as those of the West Branch-Gladwin group of moraines in the Saginaw Valley. The front ridge seems in most places like a strongly developed single moraine, and for this reason it has in the past been treated as a distinct individual and has been called the Port Huron moraine. It is of the substage order of magnitude and is, in fact, one of the best developed and most clearly defined moraines in the Great Lakes region.

After the Defiance moraine, which was traced from Ohio into Michigan as far as Adrian by G. K. Gilbert in 1870, the main moraine of the Port Huron system was the first to be distinctly recognized on the east side of the southern peninsula of Michigan.[1] Its relations to the Saginaw Bay and Lake Huron basins and to the intervening ridge of the "thumb" are so simple as to furnish an ideal illustration of the relation of the ice front to the larger elements of relief. On the "thumb," from Caro to Bad Axe and thence southward to Wadhams, it is a typical land-laid moraine, but in the central parts of the Saginaw and St. Clair valleys it is an equally perfect type of water-laid moraine, though when studied in detail it is found to be not a single ridge but a composite system.

The main moraine of the Port Huron morainic system played a more prominent part in the lake history, so far as that history has been worked out, than any other moraine in the Great Lakes region. The Huron-Erie glacial lakes had a more complicated history than those of any other basin, the principal cause of complexity being the oscillation of the ice front during the general retreat. Where the sequence of retreats and readvances was critically related to the retaining barrier of the lake waters, as it was on the "thumb" of Michigan, every movement of the ice front backward or forward affected the level of the waters. Oscillations of the ice front on

the "thumb" of Michigan did not affect the level of the waters in the Saginaw basin, but nearly every movement changed the level of those in the Huron-Erie basin. In the early stages of these waters several changes of this kind occurred, and it has been difficult to unravel the complexities which they produced.

The main moraine of the Port Huron system marks a pronounced readvance of the ice front and records one of the simplest of these changes, uncomplicated by any later or earlier ones. The ice formed the barrier which retained Lake Whittlesey, and its readvance raised the waters-of the lake more than 40 feet, submerging the earlier Arkona beaches. It was in connection with this moraine that the effects of readvance in raising lake waters were first recognized.

Besides its critical relation to the Huron-Erie lakes, this main moraine is distinguished above the others by having been traced continuously across the Great Lakes region for a greater distance than any other. Mr. Leverett describes its distribution and characteristics at points farther north and west (see pp. 302-315) and the writer has traced it eastward across Ontario into New York.

Two other fainter water-laid moraines belonging to the Port Huron system lie between the main moraines of the system and the shore. The first, the Bay City moraine, surrounds Saginaw Bay from Iosco County to northern Huron County. The other, the Tawas moraine, is a fragment which lies near the shore in Iosco and Arenac counties.

[1]Correlation of Erie-Huron beaches with outlets and moraines in southeastern Michigan: Bull. Geol. Soc. America, vol. 8, 1897, pp. 41-43.

MAIN MORAINE OF PORT HURON MORAINIC SYSTEM.

DISTRIBUTION.

In northwestern Iosco County Au Sable River cuts a trench over 200 feet deep in the drift deposits and at this point the main moraine of the Port Huron system is interrupted by a break 6 or 7 miles wide.

South of Au Sable River the moraine is spread out upon a till plain with three or four weaker ridges openly deployed. It also embraces a ridge of considerable strength along the east section of Rifle River in eastern Ogemaw County. These ridges converge toward the great bend of Rifle River in the northern part of Arenac County. The front or earliest ridge is much stronger than the others. From the Au Sable it runs westward to 7 or 8 miles east of Rose City, where it turns abruptly and runs directly south to a point about 4 miles west of Prescott.

East of this and apparently next in order of formation is a weaker, irregular morainic deposit which runs west for 5 miles into Ogemaw County and then turns south for 10 miles, ending in a till plain without clear connection with the other ridges.

Another slender ridge runs directly southwest for about 25 miles to the bank of Rifle River, 2 miles west of Melita, in Clayton Township.

From the southwest corner of Iosco County a strongly developed ridge, known locally as Maple Ridge, runs more westerly to a point 3 or 4 miles east of Melita, and also eastward 5 or 6 miles to the Au Gres River. On the same line produced, on the west side of Rifle River, a morainic ridge of moderate strength runs southwest nearly to the Arenac County line, where it turns south and runs in fainter, broken form to the northwest corner of Gibson Township, the northernmost township of Bay County. Another lighter till ridge starts from the bank of Rifle River at the bend about 3 miles north of Sterling and runs southwest to Pine River about 3 miles west of Sterling. Then after a break of 2 or 3 miles this ridge reappears and curves southward and joins the other ridge from the north in northwest Gibson Township. Outside of these ridges in the northwest part of Arenac County and neighboring parts of Ogemaw and Gladwin counties is a moraine which seems to fall in the Port Huron morainic system but which dies out in a sandy plain east of Tittabawassee River and is not recognized farther south.

In eastern Gladwin County the main moraine appears to become water-laid and it begins also to be largely covered with fine sand, which was blown over it, in part at least, from the wide sandy plain which borders it on the west, and perhaps in part also from beaches lying near its crest. Where it is water-laid, the moraine loses its relief with reference to the country around it. It runs southward through eastern Gladwin County as a broad, low ridge that controls the drainage but grows constantly less conspicuous. After entering northeastern Midland County it turns gradually southeast and follows the east bank of Tittabawassee River to Saginaw, where it ceases to be perceptible to the eye. It continues, nevertheless, in the same line along the north side of Cass River and governs the course of that stream to the vicinity of Vassar, near which it again emerges from the lake bed. North of Vassar it becomes prominent and extends directly northeast along the north bank of Cass River to the hilly interlobate region southeast of Bad Axe in southern Huron County.

In its water-laid part in the Saginaw Valley the moraine seems to be single. Five or six miles north of Caro, however, it begins to show more than one line of knolls and becomes distinctly composite. The front line keeps the more direct course and passes northeastward a little north of Cass City, north and northeast of which it is broken. The most prominent ridge back of this turns north through eastern Elmwood Township, Tuscola County, and runs past Gagetown, from which place it runs northeastward to the vicinity of Bad Axe in Huron County; but from a point 3 or 4 miles northeast of Gagetown it is much weaker. Between these two ridges, along Cass River in northeastern Tuscola and southern Huron counties, scattered detached knolls and short

ridges lie in a till plain, but no clearly developed moraine is visible.

The higher irregular ground of the interlobate tract lies principally in southeast Verona Township, Huron County, but partly also in northeast Bingham, western Sigel, and northwestern Paris townships.

In sec. 2, Bingham Township, the front ridge of the Saginaw lobe met the front ridge of the Lake Huron lobe at an angle slightly less than a right angle and just here there is a narrow depression through which Willow River flows northward.

From this point the front ridge of the Lake Huron lobe runs southeast into the north edge of Sanilac County, where it turns more southward to the north bank of Black River opposite Wadhams, 7 miles west of Port Huron. From Huron County to this point the moraine ridge is very strong, but at Black River it passes under the level of the Warren beach and thence southward it is a low, broad water-laid ridge mainly covered with sand. It crosses St. Clair River into Canada a mile north of St. Clair.

TOPOGRAPHY.

ALTITUDE AND RELIEF.

The western or front ridge in Ogemaw and Iosco counties is fairly strong. From an altitude of 930 to 950 feet in northeastern Ogemaw and northwestern Iosco counties it falls to 850 to 875 feet at the north edge of Arenac County. Its front relief is generally 50 to 60 feet and its inner relief 25 to 30 feet.

The other branching ridges in eastern Ogemaw and western Iosco counties are rather ill-defined as ridges and have low relief. The knolls are generally not over 10 to 15 feet high. Their altitude ranges from 920 or 930 feet in northwestern to slightly below 800 feet in southwestern Iosco County. Maple Ridge has an altitude of about 850 feet near the village of Maple Ridge and of about 860 feet a mile north of Melita. West of Rifle River its continuation has an altitude of from 820 to 840 feet and a relief of 40 to 50 feet. The narrow ridge northwest of Sterling has an altitude of 780 to 800 feet and its continuation into Gibson Township, Bay County, has an altitude of 825 feet, declining southward to about 810 feet before it begins to be covered with sand and gravel. The relief of these ridges is generally 20 to 30 feet.

In its water-laid part the moraine descends from about 800 feet in western Gibson Township to 700 feet about 10 miles north of Midland and to 600 feet at Saginaw. From Saginaw it rises again to 700 feet at Vassar, where it again becomes land laid. From Vassar to Bad Axe and thence south to Black River near Port Huron the Warren beach is the highest shore line on the inner or lakeward slope of the moraine, but from Vassar to Cass City the outer slope of the moraine was washed by the waters of Lake Saginaw at the level of the Arkona beaches, which are 20 to 40 feet higher. The limits of the lake waters on the two sides of the moraine in northwestern Bay County were not definitely determined, partly because the moraine shows much less change of expression in passing from land-laid to water-laid form, but mainly because the whole area is covered and obscured by sand.

Between Vassar and Gagetown the moraine has a number of knolls which rise above 800 feet and a relief of about 100 feet on both sides. The ridge has an unusually sharp and narrow crest between Watrousville and Ellington. North of Cass City the front ridge is much broken and its scattered knolls are below 800 feet.

From this point a narrow crest rising above 800 feet and in some parts to 865 feet runs continuously to the interlobate angle. The ridge which extends to Gagetown reaches above 800 feet at a number of points south of that place, but is a little lower farther north. The highest point on the moraine is on a knob just west of the cleft in the interlobate angle where the topmost point is a little above 890 feet.

The relief of the moraine northeastward from Cass City is generally nearly 100 feet on the outer slope and about 50 feet on the inner slope. In the interlobate area north of the angle the relief is generally 70 to 80 feet and the altitude 810 to 820 feet, with some points reaching 860 feet.

From the interlobate angle southeastward into Sanilac County the altitude of the moraine is 850 to 860 feet and the relief on both sides 50 or 60 feet. Southward the altitude declines very gradually to about 800 feet at Carsonville, 760 or 770 feet at Amadore, and 730 or 740 feet a mile or two north of Black River. The relief on the outer border continues about the same, except that Black River cuts deeper as it flows south.

From Wadhams to St. Clair the water-laid moraine declines from about 680 to about 625 feet; its relief on the outer slope is only 5 or 10 feet near Black River and 20 or 25 feet near St. Clair; on the inner slope its relief is slightly greater.

CHARACTER.

The front ridge of the main moraine of the Port Huron system in Ogemaw and Iosco counties is strong and has mainly swell and sag topography with scattered basins. The fainter branches east of the front ridge have comparatively low knolls and are not conspicuous as ridges; among them basins are numerous and more prominent than knolls.

Maple Ridge, in southern Iosco and northern Arenac counties, is a strong moraine with mostly swell and sag topography. It runs southwest as a high and prominent feature and terminates abruptly at the edge of the 200-foot deep ravine of Rifle River. From its end a commanding view is obtained over the lower sandy plain to the north and west.

Southwest from Rifle River Maple Ridge is not so strongly and evenly developed, but has a swell and sag topography. Where it turns south near the county line it

becomes broken and discontinuous. The fainter ridge which runs southwest west of Sterling has mainly a swell and sag topography. On entering Bay County the main ridge at first has a moderately undulating topography, but as it begins to be water-laid it becomes smooth and broad and without conspicuous surface features. Toward Saginaw it becomes so broad and flat that it ceases to be a visible ridge; shortly, however, it resumes the form of a broad, smooth ridge, and a little north of Vassar it becomes a rugged land-laid moraine with a mainly swell and sag topography of rather pronounced type, carrying some basins and a number of high, rather sharp knolls. Toward Gagetown the inner ridge is broken and irregular with mainly a swell and sag topography. Near Cass City the front ridge is still more broken, and much of the area between Cass City and Gagetown is a flat till plain bearing only scattered low knolls.

In Huron County west of the interlobate angle the front ridge is of the swell and sag type; and the area between this and the Gagetown ridge, which is much weaker, is largely a plain with only scattered low knolls.

The interlobate area east of Bad Axe is mainly composed of rather high knolls and swampy troughs. There are many small basins, but the knolls are much more prominent.

Nearly all of the moraine from the interlobate angle to Black River, 7 miles west of Port Huron, has a moderate swell and sag topography with comparatively few basins. This part of the moraine, however, is composed of three or four parallel subordinate ridges whose crests are generally quite clearly defined and have long longitudinal sags between them. Thus, though the bulky ridge is compound, its separate elements are related in the simplest possible way. There are very few basins in this part. The surface forms are excellent types of swell and sag topography.

South of Wadhams, on Black River, the water-laid continuation of the moraine is a broad, low ridge largely covered with sand.

STRUCTURE OF THE DRIFT.

THICKNESS.

In eastern Ogemaw and western Iosco counties the drift has a thickness of 100 to 200 feet. Near Tawas and southwestward to northern Bay County the drift within 5 or 10 miles of the shore is thin, varying from nothing to 50 or 75 feet. In western Arenac the thickness is about 200 feet, and along the course of the main ridge in Gladwin, Midland, and Saginaw counties it is generally 200 feet. From Saginaw eastward, however, its depth is about 100 feet to the north edge of Tuscola County, except along the high crest of the moraine northeast of Vassar, where it is nearly 200 feet. In Huron County outside of the interlobate area the drift is in few places more than 50 feet thick and at many places near the shore is very thin or absent. Near the shore in Bay County the thickness is about 100 feet. In Sanilac County the thickness along the moraine to the vicinity of Carsonville is about 150 feet and along the shore 20 to 50 feet. From the vicinity of Port Sanilac to Port Huron and St. Clair the thickness is 200 feet or more.

COMPOSITION.

In Iosco and eastern Ogemaw counties the main moraine of the Port Huron system is bowldery and contains notable amounts of gravel and sand. The land-laid parts on the “thumb” are also bowldery. But aside from these bowldery parts and the surficial sands and gravels of the beaches, the drift of this whole district is notable for the large predominance of clay in its composition.

At Tawas, Lexington, and other places near the lake shore, there are flowing wells which seem to issue from porous beds beneath the till sheet of the moraine. The beds are inclined upward inland and have their intake areas at higher levels some miles back from the shore, and the water percolates down the slope under the inclined surficial till sheet.

TILL PLAINS.

In eastern Ogemaw and western Iosco counties the area east of the front ridge of the main moraine of the Port Huron system is a till plain of considerable extent. It carries only low, undulating ridges but is characterized by a great many basins, many of them deep and a considerable number containing lakes. The lands surrounding the area carry mainly sand and gravel of low fertility, but the area itself has a fertile clay soil that promises excellent results under cultivation.

A small till plain above the level of the lake waters lies along the south side of the older moraine fragment in northwestern Arenac County. Small till plains are included between the outer and inner ridges of the moraine between Cass City and Gagetown and southwest of Bad Axe. A narrow till plain lies between the Warren beach and the inner slope of the moraine in southeastern Huron County and extends for about 10 miles southward into Sanilac County.

The lake bottom below the level of the highest beach commonly has more or less of the character of a till plain, but wave work along the lines of the several beaches has modified the surface considerably both by erosion and deposition. Considerable parts of the drift have been removed, leaving bowlders on the eroded surface, and sands and gravels have been deposited in extensive beach ridges and sand belts. The finer sediments were carried away and deposited in deep water. Where the basins were deepest, immediately in front of the ice, lake clays of considerable depth were deposited. A large area in the low part of the Saginaw Valley outside of the main moraine of the Port Huron system contains 50 to 100 feet of lake clay without stones or sand. A thickness of 90 feet was penetrated at St. Charles in a coal shaft; and 150 feet or more is reported to lie in the Lake St. Clair basin south of the moraine.[1]

OUTWASH.

While the ice front was resting on the front ridge of the Port Huron system in Ogemaw and Iosco counties, a large river followed the course of the Au Sable to the bend in northwestern Iosco County and thence went west and south along the front of the moraine into southern Ogemaw and northern Gladwin counties.

The descent of this stream was rapid, and although it probably obtained a considerable amount of sandy outwash directly from the ice front, it must also have gathered much from the erosion of its bed, for almost its whole course was through older sandy outwash deposits. It carried enormous quantities of sand into southern Ogemaw and northern Gladwin counties and spread them in a relatively thin sheet over the flat areas of that region, covering up what would otherwise doubtless have remained a fertile till plain suitable for cultivation, and covering also in all probability the Arkona beaches northward from a point 7 miles northeast of Gladwin and thus making it impossible to learn anything definite about the relation of these beaches to the main moraine in this locality.

[1]Cole, L. J., Delta of the St. Clair River: Michigan Geol. Survey, vol. 9, pt. 1, 1903, p. 14.

More or less outwash issued directly from the ice along its front, but no notable deposit is known with certainty, except in Sanilac County, where a thin, narrow sheet of sandy outwash spreads like an apron from the front of the moraine from Amadore northward nearly to the Huron County line. Although this deposit is relatively small and narrow, its southern part buried two of the beaches of Lake Arkona.

The total absence of outwash along some parts of the moraine front is more remarkable than its presence in other places. From a mile west of Amadore southward to the junction of Mill Creek with Black River, no outwash whatever is visible, and the condition of fragments of the lower Arkona beach, which lie in actual contact with the base of the front slope of the moraine, proves conclusively that none was ever deposited.

GLACIAL DRAINAGE.

UBLY CHANNEL.

While the ice front was resting on the main moraine of the Port Huron system the Huron-Erie basin was occupied by Lake Whittlesey. The lake discharged through a long, narrow bay, called Black River Bay, which extended from a 3-mile entrance between Spring Hill and Zion, 14 miles northwest of Port Huron, northward for 50 miles, nearly to Ubly. From a swamp at the head of this bay the outlet ran close along the ice front in the reentrant angle on the “thumb,” and the channel now marking its course lies close along the front of the moraine from 3 miles east of Ubly to Cass City, about 18 miles on the course of the channel, where it enters Lake Saginaw.

The Ubly channel is short, but it is one of the large, important channels of the Great Lakes region. Its head is 3 miles east of Ubly, in a swamp whose waters flow northwest to the North Branch of Cass River. Two miles southeast of the divide at the head of the channel the swamp is less than a mile wide, but on the divide its width is about 2 miles and it continues with this width to the bend of Cass River in sec. 15, Bingham Township. Here the channel turns sharply southwest through a passage not over three-fourths of a mile wide and continues thence past Ubly to Cass City with a width of 1 to 11/2 miles.

A high till ridge just east of Ubly separates it from the head of the channel at the divide. On the west side of this ridge another narrower passage, floored with sandstone in nearly horizontal beds, runs northwest from the Black River swamp a mile or two southeast of Tyre and once carried a large body of water to the main channel at Ubly. Tyre stands on the floor of this branch channel.

The floor of the Ubly channel shows more pronounced evidences of scour by a large river than do most of the glacial channels. Comparatively little of it is swampy, this character being confined mainly to its upper and lower reaches. The rest of it is floored with immense numbers of bowlders and at places with pebbly or gravelly bars, some of them 8 or 10 feet high, whose shapes show distinctly that they were produced by a strong current flowing southwest.

At Holbrook, in northeast Greenleaf Township, a passage opens into another channel lying close south of the Ubly.

Cass City is built on a gravelly terrace which appears to be partly the product of a glacial stream coming from the northwest through the moraine and partly a delta deposit of the Ubly outlet river.

The present altitude of the floor of the channel is about 800 feet at its head and about 740 feet a mile or two east of Cass City. The channel lies nearly in the direction of maximum uplift, about N. 22° E., and runs almost directly down the slope of the tilted land. From its present fall of nearly 60 feet it is necessary therefore to subtract 15 or 16 feet in order to find its original descent of 40 to 45 feet. This original descent is the difference in the altitudes of Lakes Whittlesey and Saginaw and indicates the amount that the Huron-Erie waters were raised by the readvance of the ice front to the front ridge of the Port Huron morainic system.

CUMBER, HAY CREEK, ARGYLE, AND BAD AXE SPILLWAYS.

The Cumber, Hay Creek, Argyle, and Bad Axe spillways appear to have been uncovered in successive order from south to north during the retreat of the ice front, and all of them are probably somewhat older than the Ubly channel, for they were made when the ice was beginning its retreat to a position farther north than that marked by the Port Huron system. The Ubly channel was made

only when the ice front had readvanced to the position of the main Port Huron moraine. The retreat and readvance of the ice front at this time will be more fully discussed later. (See pp. 362-385.)

Cumber spillway.—The Cumber spillway, which lies close south of the Ubly outlet, is in its lower three-fourths almost as well developed as the Ubly. In its head ward part it is not maturely developed. It opens westward out of Black River swamp south of Tyre through two or three head branches whose floors are of stony till and were not much deepened although considerably widened by the flow of the lake waters. The Cumber spillway is particularly well developed in western Austin and southwestern Greenleaf townships, where the stony till ridge between the Ubly channel on the north and the Cumber on the south is hardly half a mile wide and seems clearly a remnant left from the scouring of the two channels. Rock ledges are exposed in it just east of Holbrook. The lower part of this channel in southwestern Greenleaf is as finely developed as the Ubly channel; in it is located the "stone wall"[1]—a small rampart ridge of bowlders produced apparently by the onshore shoving of ice in a shallow bay or lake—described by Gordon and others.

The Cumber channel extends southwestward to the middle of Novesta Township, Tuscola County, and may connect with the bowldery belt in Novesta and Wells townships and farther on with the East Dayton channel. This correlation, however, seems very doubtful in view of the differential uplift of the land. The flat ground upon which it emerges has now an altitude between 740 and 745 feet, which is about the same as that of the head of the East Dayton channel. Before the elevation of the land the ground in Novesta Township was about 15 feet lower, which would leave little or no declivity toward the southwest and little chance for scour along the line of the bowlder belt.

Hay Creek spillway.—Opening from the swamp east of Frieburger another smaller spillway runs west to a point south of Cumber and thence southwest down Hay Creek to the middle branch of Cass River. The lower part of the Hay Creek spillway was deeply cut and has a swampy floor, but it is relatively narrow and its headward parts are undeveloped.

Argyle spillways.—In Argyle Township two headword branches of Cass River join and flow westward. Although they have no well-developed channel they flow in valleys which seem much too large for them and which evidently served as temporary spillways.

The south branch of Cass River follows a line of swamps which may be in part an esker trough, but which may have been a temporary spillway joining the Argyle spillway at Shabona. The swamp forks in the southeast part of Lamotte Township, one branch going northwest past Novesta; neither branch shows distinct scour, but both may have served as very temporary spillways.

Bad Axe spillways.—When the ice front began to recede from the Port Huron morainic system it uncovered ground slightly lower than the col at the head of the Ubly channel and permitted the formation of two winding, swampy passages that led through the interlobate hills between the Ubly channel on the south and the edge of the interlobate high ground at Bad Axe and Verona Mills on the north. These channels are only 70 to 80 rods wide, but their bowldery, swampy floors show the scour of the stream that passed through them. One of them is about 4 miles north of Ubly and passes close to Wadsworth with an altitude of 785 to 790 feet. The other somewhat wider channel lies about a mile south of Verona Mills. It seems evident that these channels were occupied for a relatively short time and that they probably divided the overflow with the Ubly channel.

[1]Gordon, C. H., Geological report on Sanilac County: Michigan Geol. Survey, vol. 7, pt. 3, 1900, pp. 18-20. Taylor, F. B., Bull. Geol. Soc. America, vol. 8, 1897, pp. 43-44.

The most important of these transitory channels is a still later one which runs along the base of the hills north of Verona Mills and, turning in a direction a little south of west, passes just north of Bad Axe. This channel is a mile wide and is a well-marked scoured depression with a bowldery floor. It was formed when the ice front rested on the ridge which runs along its north side. This channel probably carried the whole discharge, leaving the Ubly channel dry. At this time a long, narrow, shallow lake, running southeast from near Verona Mills into Sanilac County, covered the flat ground between the ice front and the recently abandoned moraine. This lake was not a part of Lake Whittlesey, but was an independent though very short-lived body. During this same time two or three similar shallow lakes lay on the west side between Bad Axe and Gage town. The waters of all these channels and lakes finally reached Lake Saginaw through the transverse channel from Gagetown to Cass City.

At the last stage, however, the water appears to have taken a different course at the southwest, for between Popple, Rescue, and Gagetown, and extending several miles farther southwest, the inner slope of the latest ridge of the Port Huron morainic system is heavily cut at or a little above the level of the Warren beach, making a steep bluff which extends for many miles and seems much too great to be attributed solely to the waves of Lake Warren, especially when it is noted that scarcely any other part of the Warren shore presents a wave-cut bluff. It seems certain that during the last stand of the ice along this ridge the water, coming probably from the Bad Axe spillways, found a temporary constricted passage between the ice and the morainic ridge, and it was mainly the cutting of that stream that made the bluff. The gravels gathered from this cutting were carried southwestward toward Vassar. Later the waves of Lake Warren, working at nearly the same level, did some further cutting at the base of the bluff, but this effect was probably not great, for at some places the waves did not reach the bluff. At the same time, besides contributing considerable fresh gravel to the deposits near Vassar, the waves worked over those previously deposited by the temporary river. The cutting of the inner slope in this

stretch is much like that which affected the Birmingham moraine at Romeo. (See p. 284.)

BAY CITY MORAINE.

Inside of the main moraine of the Port Huron system of the Saginaw basin and 10 to 12 miles nearer the lake runs another much fainter morainic belt known as the Bay City moraine. Its faintness suggests that it is a subsidiary ridge of the Port Huron system, but it is all deeply water-laid and its faintness alone is not a safe criterion. In its distribution it appears to be independent, though it seems hardly likely that it marks a substage.

A moraine which is doubtfully correlated with the Bay City moraine begins 5 or 6 miles northwest of Tawas on a rugged slope of bowlder clay which forms a sort of retaining wall for the south part of the great delta of Au Sable River. The moraine runs slantingly down the slope from about 750 feet altitude to about 650 feet. From its top the edge of the delta extends away north and northwest as a sand plain. The moraine is gullied by ravines that run down the slope, but it seems to have had a swell and sag topography considerably modified by erosion.

To the southwest for 5 or 6 miles this fragment gives place to a sandy country, but it may be continued by a low stony till ridge which sets in close east of Turner and Twining in Arenac County. This ridge trends southwest in direct line with other faint knolls, near Omer and Standish, which clearly belong to the Bay City moraine.

From this place the moraine continues southwest into Bay County, bending gradually around to the south and southeast and keeping 5 to 8 miles from the shore, and crosses Saginaw River at Bay City as a distinct though faint ridge. From Bay City it bends southeast 7 or 8 miles, passing around the south side of the swamps of Quannicassee. Then from the southeast corner of Bay County it runs northeast through Tuscola County, keeping 5 to 6 miles from the shore and passing Fairgrove and Unionville. In southwestern Huron County it is weaker, but it reappears in fair strength 4 miles north of Elkton, beyond which it is represented by an ill-defined bench and a bowldery belt, which runs northeast through Meade Township into eastern Dwight Township and then swings southeast through Huron Township. A shore line connected with the bowldery belt is much more bowldery where it lies on the morainic bench than it is elsewhere.

The Bay City moraine is water-laid throughout. Its altitude is 750 to 650 feet west of Tawas and about 640 feet at Turner and Twining in Arenac County. It declines very gradually southward to 605 or 610 feet at Bay City. Its relief is very low, generally under 10 feet. Northeastward from Bay City its altitude rises gradually to about 655 feet 3 miles north of Elkton.

TAWAS MORAINE.

A narrow faint ridge of stony till, beginning at the lower edge of the sandy deposits south of Au Sable River, runs a little west of south through Wilber Township, passing west of Tawas Lake, to the western edge of the village of Tawas in Iosco County. This ridge, known as the Tawas moraine and regarded as a member of the Port Huron morainic system, runs southward in fair strength to Alabaster and thence in fading form into northeast Arenac County. About 5 miles west of Tawas a few very low knolls with some stones trend northeast and southwest and seem to mark a faint earlier moraine.

The altitude of the Tawas moraine in Wilber Township is 625 to 630 feet, and it declines southward to 600 feet or less in eastern Arenac County. Two or three miles north of Alabaster it rises to 640 feet. Its relief near its north end is 15 to 20 feet, but declines southward to 5 or 10 feet. Where it is partly cut away along the shore between Tawas and Alabaster its relief is 15 to 20 feet on the outer slope.

About a mile south of Port Austin and near the shore in northern Huron Township three or four prominent knolls suggest by their altitude and location a correlation with the Tawas moraine.

CORRELATIVES OF THE PORT HURON MORAINIC SYSTEM IN ONTARIO AND NEW YORK.

By FRANK B. TAYLOR.

Since 1893 the writer has made occasional studies of the Pleistocene formations in Ontario, chiefly on the southwestern peninsula. Although the results are still somewhat fragmentary they are fairly complete in some areas and show the general plan of the terminal moraines of the region.[1]

The Port Huron morainic system on the east side of Lake Huron has the same habit of expression that it has on the “thumb” and in the Saginaw Valley in Michigan. In a few places it is composite, but generally it forms a single strong ridge. It has been traced continuously from Mooretown on St. Clair River, where it is water-laid and faint in its expression, past Wyoming, eastward north of Arkona, northward west of Ailsa Craig to the bend of Maitland River, and northeastward along the north side of this river to a point 5 or 6 miles north of Wingham. Beyond this it has been identified at several places as far as Markdale and beyond that has been mapped in detail to the escarpment west of Collingwood.

In the basin of Lake Ontario the identification of this moraine has been made out satisfactorily in western New York and across the Niagara peninsula to the vicinity of Hamilton, and it is known with approximate accuracy northward along the escarpment to a high angle on the great promontory west of Collingwood. The identity of the moraine was made sure by its relation to

the Whittlesey, Arkona, and Warren beaches at Marilla and Alden, 20 miles east of Buffalo.

[1]The moraine systems of southwestern Ontario: Trans. Canadian Inst., vol. 10, 1913.

In the Ontario basin and the east end of the Erie basin this morainic system has a different expression from that which it shows in the Lake Huron basin. Its component ridges spread apart on the plain after the manner of the slender ridges of the West Branch-Gladwin group of moraines in the Saginaw Valley. It would seem probable, therefore, that three or four or perhaps more of the slender moraines in western New York and on the Niagara peninsula in Ontario form a group which is as a whole the equivalent of the massive moraine of the Port Huron morainic system on the "thumb" of Michigan. When the ice front was resting on this moraine on the "thumb" it made at least three or four subordinate oscillations before it uncovered lower ground and allowed the waters of Lake Whittlesey to fall to lower levels. At the east end of Lake Erie these three or four ridges were not set close together but were deployed at considerable intervals, and during the making of the first three or four the level of Lake Whittlesey was not affected. Apparently the Alden moraine was the last ridge made while Lake Whittlesey kept its level. This moraine is therefore believed to be the correlative of the last of the secondary ridges on the "thumb" which held Lake Whittlesey up to its level. The eastern equivalents of the Port Huron morainic system include in all probability the Gowanda, Hamburg, Marilla, and Alden moraines as described by Mr. Leverett.[1]

PORT HURON MORAINIC SYSTEM IN NORTHERN HURON AND NORTHERN MICHIGAN BASINS.

By FRANK LEVERETT.

GENERAL RELATIONS.

In the northern part of the southern peninsula a complex group of moraines appears to continue the Port Huron morainic system to the north and west from the Au Sable Valley, where Mr. Taylor's description ends. (See pp. 293-301.) It embraces all the moraines and associated glacial features found on the slopes descending toward the northern end of Lakes Huron and Michigan from the great table-land in the northern part of the southern peninsula. The moraines of this system in places show a discordance in relation to the earlier ones such as might result from a readvance following a marked recession of the ice border. Further evidence that the moraines of this group are markedly younger than the ones outside is shown by the relation of the moraines in the Michigan basin to the beaches of Lake Chicago. It is by means of this relation to the beaches that correlations have been made with moraines on the Wisconsin side of Lake Michigan.

DISTRIBUTION.

In the northern part of the southern peninsula the border of this morainic system follows the northern edge of the high table-land in which Au Sable and Manistee rivers rise. It is accompanied by a great outwash gravel plain or apron that bears evidence of a prolonged stand of the ice border at this culminating position. From the Au Sable Valley in eastern Oscoda County the outer moraine leads northwestward across Montmorency to northwest Otsego County, where there was a reentrant between the Huron and Michigan lobes. Thence it goes southwestward through Antrim and Kalkaska counties, keeping just east of the line of the Grand Rapids & Indiana Railway, leads westward across southern Traverse County, and turns south through eastern Manistee County, keeping a few miles back from Manistee River throughout its course in these counties to the latitude of Manistee, where it crosses the river, beyond which it is continued only as disjointed ridges. These ridges lead southwestward nearly to the shore of Lake Michigan in western Mason County at the east end of Hamlin Lake, then make a southeastward detour into southern Mason County and come back to the shore of Lake Michigan south of Ludington. In Oceana County they are in places banked against the western end of the great spur of the Lake Border system (p. 223). South of this spur are two ridges. One, known as the Whitehall ridge, lies 3 to 5 miles back from the shore of the lake and is traceable past Whitehall to Muskegon, south of which it passes into Lake Michigan. West of Whitehall in northern Muskegon County a second ridge, which seems closely related to the outer one, appears for a few miles along the shore of Lake Michigan; it was not recognized farther south than White Lake.

On the Wisconsin side of Lake Michigan the correlative of this moraine seems to be found in a deposit of red till which covers a narrow strip on the coast from Milwaukee northward to the base of the Green Bay peninsula, where it curves back to the southwest and north into the Lake Winnebago basin, passing to the south end of that lake. Its course has not been fully determined from Lake Winnebago northward, but it probably correlates with a moraine which crosses the State line of Wisconsin and Michigan east of Florence, Wis., and runs northward along the east side of Michigamme River about to the latitude of Channing, where it turns westward at a reentrant between the Green Bay lobe and the more western portion of the ice field. Studies in 1910 in the Northern Peninsula of Michigan, northern Wisconsin, and northeastern Minnesota seem to give warrant for correlating this morainic system with one which sweeps around the head of Lake Superior, but the facts can be fully established only by further field work.

[1]Mon. U. S. Geol. Survey, vol. 41, 1902, pp. 673-685. See also Niagara folio (No. 190), Geol. Atlas U. S., U. S. Geol. Survey, 1913, fig. 8, p. 17; also Trans. Canadian Inst., vol. 10, 1913, map opposite p, 23.

Present knowledge at least suggests that the glacial readvance marked by the Port Huron morainic system

continued all the way from New York to Minnesota or entirely across the Great Lakes basins. A similar readvance is indicated in the ice field which covered the Red River basin west of the Great Lakes, a basin which subsequently held Lake Agassiz.

TOPOGRAPHY.

CHARACTER.

Considerable variation is displayed by this morainic system in its circuit of the northern Huron and northern Michigan basins. On the slope toward the Huron basin lie great morainic spurs extending toward the lake from the outer ridge of the system and isolated island-like tracts of moraine surrounded either by sand or till plains. (See Pl. VII.) In Oscoda County, and to some extent in Otsego County, plains separate the spurs or transverse ridges from the outer ridge of the system, but in the intervening district in Montmorency County the spurs are very closely connected with the outer moraine. Toward Lake Huron from this outer moraine the ridges become less closely aggregated and much of the surface is occupied by till and sand plains.

In the reentrant angle between the Huron and Michigan lobes in northern Otsego and eastern Charlevoix counties morainic topography is prominently developed as far north as the lowland which leads from Little Traverse Bay eastward to Burt Lake, and very prominent morainic tracts extend north of this lowland, one of them reaching the shore of Lake Michigan north of Little Traverse Bay.

This morainic system on the slope toward Lake Michigan and Grand Traverse Bay differs in one striking particular from its expression on the slope toward Lake Huron. The outer moraine of the Lake Michigan portion is a distinct narrow ridge paralleled throughout much of its length by a second definite ridge, from which it is separated by the outwash and border drainage connected with the second ridge. Morainic spurs such as occur on the Huron slope are also conspicuous on the Lake Michigan slope, but they are related to the second instead of to the outer ridge of the system. The striking parallelism of these ridges is thought to indicate that the second ridge is a close successor of the outer one and a part of the same system.

The second ridge is practically continuous from eastern Charlevoix County southwestward to the head of Grand Traverse Bay. Southwest from Grand Traverse Bay, however, it consists of a broken chain of ridges leading across eastern Benzie County through an extensive gravel plain, from the western side of which prominent transverse ridges extend across southwestern Leelanau, Benzie, and Manistee counties to the shore of Lake Michigan, southwestward from Little Traverse Bay to Grand Traverse Bay, and on the borders of the latter conspicuously developed drumlins and drumlinoidal ridges lead either into the second moraine or somewhat later morainic ridges on the inner border of that moraine.

On the Huron as well as the Lake Michigan slope great depressions extend back between the morainic spurs and transverse ridges to the inner border of this morainic system. Several on the Lake Michigan slope are occupied by narrow, deep lakes, and such lakes also occur on the Huron slope in Cheboygan County and northern Alcona County, but others are occupied by sandy plains. It is probable that these great depressions were occupied by tongues of ice during the decadence of the ice sheet. (See p. 315.)

In northeastern Manistee County the outer moraine is split into several members which become successively lower from east to west and which with the intervening plains give a steplike appearance, the morainic slope forming the riser and the gravel plain the tread.

The broken ridges leading from Manistee to Muskegon County show great variations in strength, their relief ranging from about 150 feet above the bordering plains down to swells 10 to 20 feet high. The most prominent are south of Ludington and in southern Manistee County.

RELIEF.

On the outer border the moraine which marks the limit of glacial readvance has (somewhat surprisingly) a general relief of only 20 to 40 feet above the table-land outside. The crest of the moraine is close to its outer edge and the knolls along it are only 15 to 30 feet high. Similar small knolls are distributed over the surface of the great spurs on the inner slope.

The second ridge on the Lake Michigan slope is also inconspicuous on its outer border, in most places rising only 10 to 20 feet above the narrow gravel plain that lies between it and the outer ridge. In this respect it contrasts strikingly with the inner border relief of the outer ridge, which is 150 to 200 feet along much of its course from northwestern Otsego County to the crossing of Manistee River east of Manistee. The gravel plain is like a terrace built up along the slope at a level 150 to 200 feet below the crest of the outer moraine.

On the inner border the relief is generally great. The spurs and ridges stand 150 to 300 feet or more above the intervening depressions.

STRUCTURE OF THE DRIFT.

The surface portion of the drift, as exposed in ravines, road gradings, and other shallow excavations, is largely till with a liberal admixture of stony material. Bowlders are rather numerous both on the surface and in the upper part of the till. The wells and deep ravines indicate that the stony till changes to sand at moderate depths along a considerable part of the morainic system, and, in the inner border district, especially on the Lake Michigan slope, to a fine silt or clay, which bears some resemblance to a lake deposit. (See p. 314.) The glacial material referable to this readvance of the ice forms therefore but a thin coating over water-laid deposits of great depth.

The color of the till shows considerable variation, some of it being distinctly red and other parts brown or yellow in the oxidized portion and blue in the unoxidized. The red color appears to be due to the incorporation of material from red rock formations in the Lake Superior basin and not to high oxidation in postglacial time. The red portion is about as calcareous as the brown and yellow. Where the underlying rock formations are of limestone or blue shale, as in the district between Little Traverse and Grand Traverse bays, there is less red drift than in neighboring districts to the north and south, where these rock formations are so deeply buried as to have made little or no contribution to the material in the till. It is not improbable, therefore, that local limestone and shale have served to give the brown and blue tills a distinctive color and to disguise the ingredients derived from the red rock formations.

On the Wisconsin side of Lake Michigan the correlative drift material is generally red. It also contains a much larger amount of fine silt or clay than is present in the surface portion of the drift on the east side of the lake or in ordinary bowlder clay. It seems to be largely derived from lacustrine silts, which were gathered up and redeposited by the ice with the addition of a little stony material very irregularly distributed.[1] Chamberlin made reference to this deposit in his work on the geology of Wisconsin and interpreted it to be the product of a lacustrine submergence that followed the retreat of the ice. Alden, however, has determined that it was laid down in large part by ice and that its limits mark the extent of the glacial readvance. The red color is as pronounced in Wisconsin as in the reddest phases in Michigan. The path of the ice which reached Michigan on this interpretation seems to have led through less heavy deposits of lacustrine silt than that which reached the Wisconsin side of the Lake Michigan basin. Possibly the Michigan side owes the redness of its material entirely to the incorporation of material derived directly from the rock formations in the eastern part of the northern peninsula.

[1]Two mechanical analyses of samples collected by Alden near Fond du Lac, Wis., made by the Bureau of Soils, United States Department of Agriculture, in 1910 show 41.3 and 51.5 per cent, respectively, of material below 0.005 millimeter. A lacustrine clay from Sauk County showed 40.9 per cent, and two samples of the burl-colored ordinary Wisconsin till near Oshkosh show only 8.2 and 7.6 per cent. It thus appears that the red drift is largely made up of fine lacustrine material.

OUTWASH.

The outer moraine is accompanied by a broad outwash apron, one of the best developed in Michigan. Its general width is 5 or 6 miles and it is present along nearly the entire length of the outer moraine from eastern Oscoda County around to the border of Lake Michigan in Mason County.

Numerous small basins and some large ones lie in this gravel plain, and some of them contain lakes. Otsego Lake, one of the largest lakes in the interior of Michigan, lies south of Gay-lord, partly in this outwash apron and partly in a depression between drift ridges of earlier date. Possibly this lake is in a valley that was blocked at the north by the deposition of the outwash.

Outside the second moraines from the reentrant angle between the Michigan and Huron lobes near the corners of Charlevoix, Cheboygan, and Otsego counties the drainage was directly southwestward to the bend of Boardman River in southern Grand Traverse County through a plain ranging in width from 2 miles to about 8 miles. From Boardman River the drainage continued southwestward past Interlochen and down Betsey River to Thompsonville, where it turned southward down Bear Creek valley to Manistee River, and then led southwestward through a series of gravel and sand plains that follow the line of the moraine. The material in this outwash belt is fine gravelly sand, very little coarse gravel being present in the line of the main channel. In the recesses west of Traverse City the outwash is in places of coarse material, indicating vigorous discharge, as might be expected from the steepness of the descent. The altitude in the reentrant angle exceeds 1,200 feet, and the glacial drainage channel drops to about 1,000 feet at Kalkaska in a distance of 30 to 35 miles, to 800 feet in the next 40 miles, and to about 700 feet in 20 miles more. This drainage, it should be remembered, is in a region which has suffered northward differential uplift (see pp. 430, 439) of 75 to 100 feet between the southern and northern ends of the channel, which would reduce the original rate of fall about 20 per cent. The effect of the high gradient is probably largely offset by the breadth of the tract through which the waters found their passage. They were probably split up into several streams of relatively small volume and were lacking in vigor notwithstanding their rapid descent.

Southeastward from the reentrant angle the drainage seems to have made its way through gaps among the morainic tracts of northeastern Otsego, central Montmorency, southwestern Alpena, and central Alcona counties to join the border drainage on the northwest side of the Saginaw lobe. These gaps are filled with fine sandy material denosited apparently under ponded conditions or by rather sluggish streams.

INNER BORDER.

HURON SLOPE.

DISTRIBUTION OF MORAINES.

Several ridges of morainic type lying some distance north of the morainic system trend northwest and southeast, approximately parallel with the main system, but no continuous morainic belt traverses the entire length of the northern Huron slope. The isolated short morainic ridges lie so far out of line as to make their correlation with one another uncertain; in fact they seem likely to have been developed at different times in the retreat of the ice border. Some are arranged in an overlapping series, showing successive development instead of strict contemporaneity. A series of three lies in southeastern Cheboygan and southwestern Presque Isle counties. (See Pl. VII.) Southwest of Rogers, in

Presque Isle County, there is also a double moraine of considerable prominence, yet neither member can be traced for more than 7 or 8 miles, both fading out into sandy plains or gently undulating till tracts.

North of Burt Lake a very prominent moraine has points that reach 900 feet and a breadth of 3 to 4 miles. North of this and separated from it by only a narrow sand plain a narrower morainic ridge rises above the 800-foot contour. A complex system of disjointed ridges extends from Mullet Lake southeastward across Cheboygan and Presque Isle into Montmorency County, the highest rising above the 900-foot contour. North of Black Lake in eastern Cheboygan and northwestern Presque Isle counties a very conspicuous morainic belt about 5 miles long rises above the 800-foot contour. Much of the double moraine southwest of Rogers also rises above the 800-foot contour. From northern Presque Isle County southeastward into southeastern Alpena County the morainic topography shows very little development, but west of Devils Lake, in southeastern Alpena County, a conspicuous moraine sets in and is traceable southeastward to Harrisville and thence southward nearly to southern Alcona County as a land-laid moraine. Farther south its expression is much milder, and it appears to have been formed at the border of Lake Warren (p. 392). It probably finds a continuation southward in either the Bay City or Tawas moraines, but the great width of the gap at Au Sable River makes correlation difficult.

The surface of the prominent morainic belts just noted presents a close aggregation of knolls and basins which give the moraines strong expression. It seems remarkable that moraines having such strong relief and such strong surface expression should be so discontinuous or have such fragmentary development.

From a point west of the middle of Devils Lake the inner slope of this moraine is heavily cut, producing a great bluff extending most of the way to Harrisville. This cutting has been attributed by the authors solely to the waves of Lake Algonquin, but it is perhaps a question whether it may not be due in part to a river flowing between the ice and the moraine, as was the case at Romeo and probably at Gagetown. (See pp. 284, 300.) The locality was studied before those at Romeo and Gagetown and has not been revisited.

Most of these morainic ridges consist largely of loose-textured drift, with considerable stony as well as sandy material. Clayey till is developed in only a few places, commonly on the inner or northeast slope of the morainic ridges. There is, however, considerable clayey till in the prominent morainic line in southeastern Alpena and eastern Alcona counties.

CHEBOYGAN MORAINE.

A very narrow morainic ridge scarcely one-fourth mile in average width, known as the Cheboygan moraine, is traceable from Cheboygan northwestward to Mackinaw City along the south side of the Straits of Mackinac, half a mile to a mile back from the shore. The ridge is also traceable eastward from Cheboygan for about 3 miles through the southern part of secs. 5, 4, and 3, T. 37 N., R. 1 W., and the ice border appears to have continued east-northeastward to the south part of sec. 32, T. 38 N., R. 1 E., as an ice-contact face between a bowldery till plain and a high sand plain to the south. Bowldery strips which run eastward for several miles farther probably represent the continuation of the border of the ice; their mapping is incomplete, but they are known to extend into the north part of T. 37 N., R. 2 E., Presque Isle County. The portion of this moraine and bowldery area east from Cheboygan lies within 3 miles of Lake Huron, at a very slight elevation above the lake level.

Although this moraine was formed at a level much below that of Lake Algonquin, the beaches of which are found on the uplands a few miles to the southwest, it is a remarkably distinct ridge, with well-defined knolls and greater irregularity of surface than is common in a water-laid moraine. It apparently marks the southern edge of a lobe of ice which came into the northern end of the Huron basin from the northern peninsula of Michigan and appears to be the youngest moraine on the southern peninsula.

ESKERS.

Several short eskers were noted in the reconnaissance made on the Huron slope in Cheboygan, Presque Isle, and Alpena counties. With the exception of one in central Alpena County, which is about 10 miles in length, none were observed which exceed 3 miles. It is not improbable, however, that the mapping of eskers is incomplete; it is difficult to trace such small ridges through forested areas, and the lines traversed by the writer were at such wide intervals that eskers might easily be present in the intervening tracts without being observed.

The esker in central Alpena County sets in at Thunder Bay River about 2 miles east of Long Rapids and runs southward through T. 31 N., R. 6 E. For a couple of miles at the northern end it has considerable complexity, there being in places three ridges side by side. It shows also a plexus of ridges in secs. 2 and 11, T. 30 N., R. 6 E. Its highest part is in secs. 2, 10, and 11, T. 30 N., R. 6 E., where points stand 50 to 75 feet above the bordering plain; but its ordinary height is about 25 feet. It trends west of south and terminates in the northern end of a great morainic tract which crosses southwestern Alpena County. This trend differs from that of the drumlins to the east, which bear north-northwest and south-southeast, but it nearly agrees with that of two drumlinoidal hills to the west. It seems not unlikely, therefore, that the esker represents the direction of the ice movement in the district which it traverses. Its northern portion has been opened at several places for gravel, which is found suitable for road ballast. Its southern end is somewhat more sandy and is less extensively opened.

An esker about 3 miles in length leads southward from La Roque station on the Detroit & Mackinac Railway

through sec. 31, T. 34 N., R. 5 E., and secs. 6 and 7, T. 33 N., R. 5 E., its course being 20° to 25° east of south. It is a nearly continuous, very sharp ridge, about 30 feet in height, composed of fine gravel apparently suitable for road ballast.

About 5 miles west of La Roque a very prominent gravelly ridge is crossed by the Detroit & Mackinac Railway in a cut nearly 75 feet deep. This ridge is more massive than the ordinary esker and has an irregular surface much like a moraine, but seems to be composed almost entirely of gravel and sand. It runs southward from the railway about 3 miles along the east side of Oqueoc River and occupies a width of about one-half mile. Farther south a rolling gravelly belt of still greater width leads through the western part of T. 33 N., R. 4 E., with a trend very nearly the same as that of the La Roque esker. It may therefore mark the course of subglacial drainage as an esker does.

Some small eskers cross the State road from Onaway about 8 miles west of that village in the northeast part of T. 34 N., R. 1 W. The easternmost runs a little east of south through the SW. ¼ sec. 1. West of it a very prominent esker with similar trend was traced northward a little beyond the township line from sec. 2 into sec. 35. Possibly both eskers are continued beyond the limits noted.

DRUMLINS.

Two widely separated drumlin areas lie on the Huron slope, one being east of Mullet Lake in Cheboygan County and the other 50 to 60 miles to the southeast in central Alpena County. None were noted in the intervening district, but as it is a forested region and was not closely traversed, some may yet be discovered.

The drumlins east of Mullet Lake are in secs. 4, 5, 8, 9, 15, 16, 21, 22, 23, and 27, T. 36 N., R. 1 W., opposite the northern part of the lake. They are only 15 to 20 feet in height, less than a mile in length, and but one-eighth to one-fourth mile in width. They trend northwest and southeast, or nearly parallel to the neighboring morainic ridges. They are in a low tract considerably below the level of Lake Algonquin and must have been covered by the waters of that lake after the ice had receded from this region. They are composed of a stiff clayey till, and their surface, as well as that of the intervening sags, is thickly strewn with bowlders, which seem to have been deposited during the recession of the ice, being confined chiefly to tracts in which till is at the surface and being very scarce on the sandy tracts.

The other drumlin area lies a few miles west of Alpena, in central Alpena County, in a till plain west of the south branch of Thunder Bay River, at a level slightly above that of the highest beach of Lake Algonquin. The majority of the drumlins lie 6 to 10 miles southeast of Flanders, but a few are in the immediate vicinity of that hamlet. Those near Flanders rise 40 to 60 feet above the bordering till plain; most of those to the southeast rise but 15 to 20 feet above it, though some, near the northern end, rise 35 to 40 feet. The trend of most of the drumlins is north-northwest and south-southeast, but those near the southeastern end bear more to the east. The trend is about in harmony with that of neighboring striæ west and north of Alpena. It is somewhat remarkable that both drumlins and striæ bear about parallel with the moraines which lie a few miles farther west. The ice movement appears, therefore, for some unknown reason, to have been less definitely directed toward those moraines during the development of the drumlins and the striæ than is common. The drumlins are composed of clayey till and their surfaces, as well as that of the surrounding till plain, are thickly strewn with bowlders.

GLACIAL STRIÆ.

The majority of observations of striæ in this region are in Alpena County, where general southeastward movement is recorded, though one observation of southward-bearing striæ was noted a few miles east of the northwest corner of the county. A single observation made in Cheboygan County, a few miles southeast of Mackinaw City, gives a movement of S. 37° W., directly toward the Cheboygan moraine, which passes just south of the striated ledge.

LAKE MICHIGAN SLOPE.

MANISTEE MORAINE.

The Manistee moraine appears on the east side of Lake Michigan, near the city of Manistee, and follows the shore northward through Manistee and Benzie into Leelanau County. It wraps around the western end of the prominent transverse ridges which come out as headlands along this part of the shore (pp. 303-304). Between these transverse ridges the ice pushed into the lowlands for several miles from the shore of Lake Michigan, so that the moraine makes a series of loops in crossing the lowlands between the prominent ridges. Its appearance is as if the ice had made a readvance and had adjusted its border to these topographic features. The portions of the lowlands overridden by the ice are coated to some extent with till, and in some places contain lakes, the most conspicuous being Crystal, Glen, and Portage lakes. The parts of the lowlands outside the Manistee moraine are covered with sand, apparently deposited from outwash that led eastward or southeastward into the drainage of Betsey River and Bear Creek. Some of these sand plains are 20 to 30 feet or more below the level of the outwash aprons that border the eastern ends of the prominent transverse ridges, apparently indicating that the outwash aprons were eroded before the Manistee moraine was developed. It is possible, however, that a large part of this erosion was due to waters escaping from the edge of the ice either during its recession from the outwash aprons or just preceding the filling which accompanied the development of the Manistee moraine.

The altitude of the Manistee moraine is scarcely 100 feet above Lake Michigan in the vicinity of Manistee, but it rises gradually northward and is fully 200 feet above the lake level at the eastern end of Crystal Lake, in Benzie

County, and becomes still higher in southwestern Leelanau County. It there becomes more closely blended with the main morainic system, causing some uncertainty as to its line of continuation around Grand Traverse Bay. It seems likely to be merged with the earlier moraines at the outer edge of the drumlin area of the Grand Traverse region in Antrim County. The altitude there is only 200 to 250 feet above Lake Michigan and is thus consistent with the altitude attained by the Manistee moraine in western Benzie County; and, were it not that morainic developments are found in a few places nearer the shore, there apparently would be no cause to question this as the line of continuation of the Manistee moraine.

One of the best-defined loops sweeps around the head of Suttons Bay on the west side of Grand Traverse Bay, and then runs south along the west side of the latter bay nearly to Traverse City. It is from a fourth of a mile to a mile in width and stands only 100 to 150 feet above the level of the bay, or about 100 feet lower than the Manistee moraine in the same latitude on the coast of Lake Michigan. At the head of Suttons Bay it has a well-defined outwash apron on its outer or southwest border and thus bears good evidence of being a terminal rather than a submarginal feature. A more prominent moraine north of Suttons Bay may have been formed between the Lake Michigan lobe and. a branch occupying Grand Traverse Bay; this interpretation seems supported by the bordering features on the west, there being a till plain on that border that apparently was covered by the Lake Michigan lobe while this moraine was being developed. This moraine may in places reach a height as great as the Manistee moraine of southwestern Leelanau County, but its altitude is generally lower. The entire morainic strip on the west coast of Grand Traverse Bay is rather low to correlate well with the Manistee moraine and seems more likely to have been developed somewhat later as the ice shrank to a lower position. In that case it may be a close successor of the Manistee moraine.

On the peninsula between the arms of Grand Traverse Bay, as well as along the east coast of the bay, the topography is largely drumlinoidal rather than morainal down to levels corresponding to the moraine on the west side of the bay. Only near the southern end of the east side of Torchlight Lake does good morainal development appear. East of the south end of Torchlight Lake and northward on the east side of Clam Lake to the vicinity of Bellaire a moraine, which is thought to be a correlative of the Manistee moraine, is separated from the second moraine of the main system by a distinct outwash apron. This outwash apron, as well as the moraine, is much lower than the second moraine and its outwash, the moraine being 200 to 300 feet above Lake Michigan and the outwash apron about 200 feet, whereas the higher moraine and outwash have an altitude of 500 feet or more. Southeast of Clam Lake the moraine for 3 or 4 miles is only about one-fourth mile in width, but it has a relief of nearly 200 feet on its inner or western border. It is at this narrow part that the outwash apron is best developed. This moraine is not clearly differentiated from the earlier moraine around the head of Grand Traverse Bay nor in the district north of Bellaire.

On the north border of Little Traverse Bay a weak moraine, rising about 200 feet above Lake Michigan level, is in part banked against a much higher morainic accumulation and in part runs across the south end of a lowland east of this prominent moraine near the east end of Little Traverse Bay. This moraine seems to have been formed by a narrow tongue of ice that pushed eastward from Lake Michigan into Little Traverse Bay and terminated a short distance beyond the head of the bay. There is not so definite a moraine along the south side of the bay, yet in places some ridging of the drift forming a drainage divide parallel with the shore was noted. This moraine like the moraine on the west side of Grand Traverse Bay seems rather low to be correlated with the Manistee moraine, but it may be a close successor of that moraine, the precise correlative being a moraine on the edge of the tract with drumlinoidal ridges a few miles southeast of Little Traverse Bay.

The Manistee moraine probably correlates with one of the chains of morainic ridges on the Huron slope, presumably with the highest chain that has a southeastward trend. This probably should include the high morainic tracts of northern Emmet and northwestern Cheboygan counties as well as those which lead southeastward from near the south end of Mullet Lake. It may also correlate with the moraine that follows the Huron shore past Harrisville and possibly with either the Bay City or the Tawas moraine farther south and thus correlate with the closing stage of Lake Warren. Unfortunately the fragmentary development of moraines on the Huron slope leaves the exact correlation doubtful.

CORRELATIVES OF THE MANISTEE MORAINE IN WISCONSIN.

Grounds for the definite correlation of the Manistee moraine with a moraine which sets in directly opposite Manistee near Two Rivers, Wis., and leads northward along the west coast of Lake Michigan, are found in the peculiar relation of each of these moraines to the beaches of Lake Chicago. It was noted some years ago that only the third or Toleston beach of Lake Chicago is present on the slopes of the Manistee moraine, and that higher beaches are present on the earlier moraines that border Lake Michigan farther south. Similar conditions were found by W. C. Alden and the writer in the moraines in eastern Wisconsin during a field conference in September, 1910. The moraine leading north from Two Rivers has no beach higher than the third beach of Lake Chicago, which is there about 25 feet above Lake Michigan. But within a few miles south of Two Rivers, on the plain between the lake and one of the earlier red drift moraines, beaches and river deltas are developed up to about 60 feet above Lake Michigan. There could scarcely be better grounds for correlation than are presented in the relation of these moraines to the Lake Chicago beaches.

ISLANDS IN THE NORTHERN PART OF LAKE MICHIGAN.

Several prominent islands lie some miles off the eastern shore of Lake Michigan, the largest being Beaver Island and the two Manitou islands. The Fox Islands lie between these, and several other islands lie near the north end of Beaver Island. North and South Manitou and Beaver islands carry heavy accumulations of drift with morainic surface. The other islands are more largely formed of sand, and those near Beaver Island have slight outcrops of rock. North Manitou Island has two high rugged north-south morainic ridges which merge at the southern end of the island but are separated by a low tract containing a lake near the northern end. Much of South Manitou Island is somewhat less prominently morainic. Mr. Taylor reports that on Beaver Island morainic ridges trend northwest and southeast in the north and southeast parts of the island, as if formed by ice from the east, but that an area of seemingly interlobate deposition with basins and ponds lies to the southwest. All these island moraines are probably later than those formed on the mainland unless the moraines on Beaver Island correlate with the Cheboygan moraine*of the Huron lobe. Correlation across such wide strips of water is very uncertain, and the morainic features of the islands will be left with this passing notice.

DRUMLINS IN THE GRAND TRAVERSE AREA.

Distribution.—Drumlins are best developed in the district between Grand Traverse and Little Traverse bays, though a few well-developed drumlins and numerous drumlinoidal hills lie west of Grand Traverse Bay and a few drumlinoids north of Little Traverse Bay near Levering. Drumlins occur for about 25 miles inland from the borders of Lake Michigan and at all altitudes from 20 feet up to 300 feet above the level of the lake, or from 600 to about 900 feet above sea level. They are confined almost entirely to the uplands and slopes, though near Elk Rapids some were found on the low plain bordering Elk Lake. At the southeast border of the district the drumlins are closely associated with morainic knolls, and in places may be said to grade into them, some hills having a well-rounded drumlin form at their northwest end and a hummocky topography at their southeast end. Features of this sort are found on each side of the southern part of Pine Lake, and also on the borders of the south end of Intermediate Lake, both east and west of Bellaire, and thence northeastward toward the south arm of Pine Lake. From Pine Lake to Little Traverse Bay a gradual change takes place from well-defined drumlins to drumlinoidal ridges and then to elliptical but irregular-surfaced hills such as immediately border the city of Petoskey. The drumlins show their most characteristic form in the district between Pine Lake and Torchlight Lake. (See fig. 2.) Most of the ridges between Torchlight Lake and Grand Traverse Bay, as well as those on the peninsula in the bay and on the peninsula between Grand Traverse Bay and Lake Michigan, are drumlinoids rather than true drumlins, their shapes being very imperfect and their surfaces but slightly smoothed. They are, however, similar in trend and in general shape to the well-formed drumlins and are separated from each other by the smooth sags generally present among drumlins.

The drumlins vary in shape from oval forms, whose length is about one and a half times their width, to linear ridges, whose length is six to eight times as great as the width. (See figs. 2 and 3.) The great majority, however, are one-half to three-fourths mile long and one-eighth to one-fourth mile wide. The longest reach 11/2 miles. Some large drumlins have fluted slopes and resemble a small drumlin perched on a sculptured large one. Such forms are to be seen on the borders of the south arm of Pine Lake (fig. 3) and in the district between Torchlight Lake and Grand Traverse Bay. The height of few of the drumlins exceeds 60 feet and that of the majority is 30 feet or less. The smallest are only 10 to 15 feet high.

The drumlins trend south or but slightly east of south on the borders of Grand Traverse Bay, but change gradually to southeastward in the district around Pine Lake (fig. 2), corresponding very rudely to the great valleys and ridges of the region. The greatest discordance is with the south arm of Pine Lake and the west arm of Intermediate Lake, which trend south, whereas the adjacent drumlins trend considerably east of south.

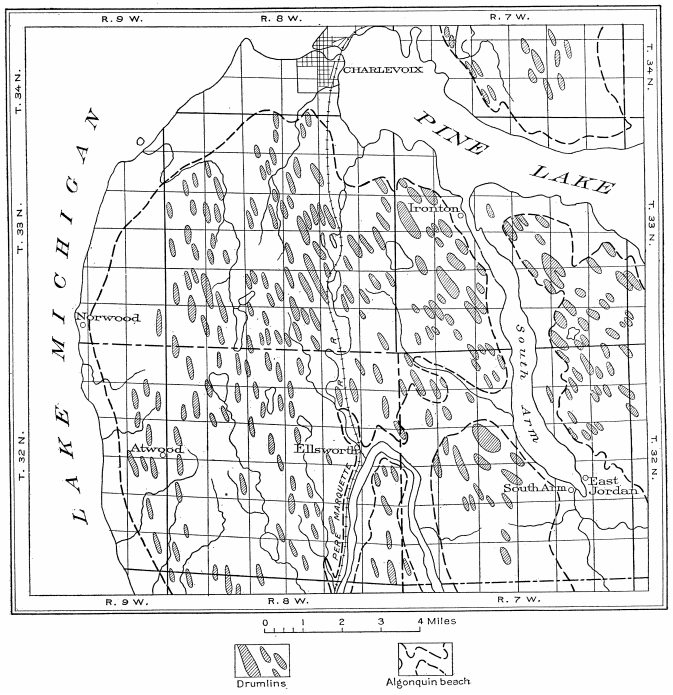


FIGURE 2.—Map of part of drumlin area south and east of Charlevoix, Mich,

Origin.—The drumlins are composed of a very evenly mixed stony till, stones being distributed through almost every cubic inch of the deposit. The majority of the stones are small, but some bowlders were noted and small rock slabs are not rare. In most of the exposures the till shows indistinct partings rudely concentric with the surface. The rock slabs do not show, as in ordinary

till, all sorts of deposition from vertical to horizontal, such as result from dropping into a deposit, but lie in the plane of the deposits, as if carried by the ice across the surface of the drumlin until lodged in a position that offered least resistance to the ice movement. Most of them show on both their upper and under surfaces striation whose direction generally coincides somewhat closely with the trend of the axis of the drumlin. The position of the rock slabs, the indistinct bedding of the deposit, and the thorough admixture of pebbles seem to bear evidence to the growth of the drumlins by slow accretion.

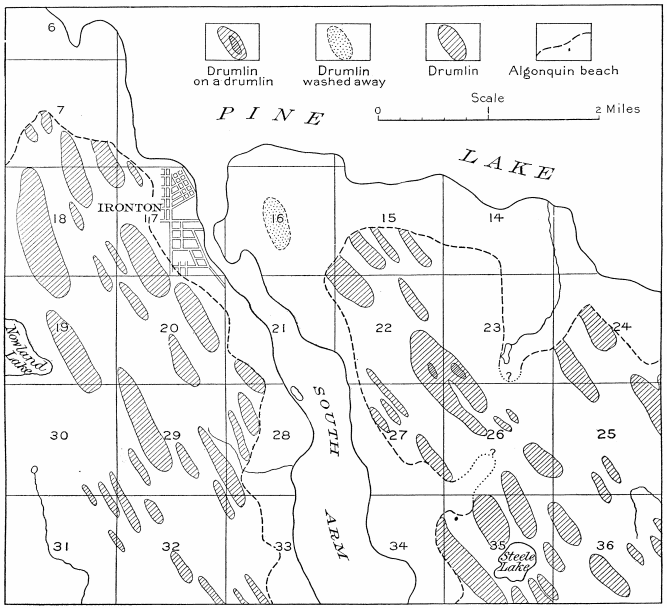


FIGURE 3.—Drumlins in T. 33 N., R. 7 W., Charlevoix County, Mich.

In certain situations, however, evidences are not wanting of sculpturing of the till into drumlin form. Shale hills, which have been shaped into drumlinoid form as a result of the ice movement over them, are found south of East Jordan in northern Echo Township, Antrim County. A till drumlin near these shale hills is partly encircled at its northwest end by a crescentic groove several feet in depth which appears to have been formed by the ice as it met the obstruction presented by the drumlin, just as similar grooves are formed on a striated surface on the stoss side of slight prominences on a rock surface. When the ice struck the drumlin it appears to have intensified its action on the plain at the base of the drumlin and thus produced the deep furrow. The flutings which some drumlins display seems likely also to be due to sculpturing effect of the ice. The drumlins which show fluting and sculpturing are restricted chiefly to places where the ice was making a rapid ascent. In places where the general slopes are downward, or where the drumlins lie on a horizontal surface, the lamination and evidences of building up by slow accretion are best displayed. It thus appears probable that the attitude of the surface passed over by the ice determined to a large extent the method of drumlin formation.

After the above description of the drumlins was written Alden presented a paper before the Pittsburgh meeting of the Geological Society of America, an abstract of which has reached the writer, in which he discussed radiation of glacial flow as a factor in drumlin accumulation. Radiation was about as marked in the Grand Traverse region as it was in the Green Bay region studied by Alden, so the drumlins under discussion may have had a like origin. The Grand Traverse region, however, does not afford so good a field as the Green Bay for testing the hypothesis. The abstract presented by Alden is as follows:

> This discussion is based on the relations of the moraines and drumlins of the south half of the Green Bay glacier of eastern Wisconsin. There is a very notable development of drumlins which are grouped in three more or less distinct sets. Corresponding to each is a set of marginal moraines believed to mark the limits of the glacial lobe during the stages when the drumlins were being formed. The outer moraine of each set marks the limit of a readvance of the ice following an interval of recession. The drumlin belts in each case are confined to distances of 30 to 35 miles from the south end of the lobe, that is, to that part where the ice was radiating widely to the curved margin of the lobe and where it was thinned in consequence of the radial spreading and of loss by melting and ablation.
>
> The computations of the probable elevation of the surface of the glacier were based on the known thickness of the ice within 4 miles of the margin where the Baraboo quartzite range was overridden and on an estimated average slope for this surface of 50 feet per mile in the first 25 miles, including the initial rise of 700 feet in the first 4 miles and allowing an average of 20 feet per mile thereafter. Deducting from these the present elevation of the land gives a thickness of ice varying from 1,450 feet over the initial part of the first drumlin belt to 450 to 830 feet where drumlins ceased to be formed within 5 miles of the limit of ice advance. The drumlin-forming ice stream had an initial width at A of 17 miles where radiation began. In advancing 15 miles this expanded to a width of 32 miles at B and at the terminal moraine the expansion gave a marginal arc of about 100 miles. Computations show that in spreading to the width at B, while at the same time maintaining the requisite thickness and low surficial slope, the cross section of the stream must have increased to 1.603 times the area of the initial section and, inasmuch as no tributary stream had added to the volume, the rate of flow must have been faster at A than at B. At C, where the drumlin formation ceased, the arc of the stream had expanded to 85 miles and the cross section was 2.325 times that at A and 1.45 times that where drumlin formation began. From these figures it is evident that the spreading of the ice under its own weight alone would not account for the remarkable expansion. Only the forward crowding of the more rapidly moving ice in the rear could have supplied the requisite volume. Though the stream expanded greatly so that friction was much increased, the remarkable development of drumlins indicates that the basal ice did not clog. Such basal movement was probably due to the ice being shoved bodily forward by the vigorously advancing ice in the rear, this forward shove being superimposed on such internal flowage as was taking place. It is believed that the application of such propulsive force in the region of the center of radiation of such a mass, which was tending to lag in every part, owing to great friction, would tend to cause the longitudinal lines to spread and so develop stress along transverse lines. These stresses, though perhaps not causing the actual opening of longitudinal crevasses, would facilitate spreading of the ice

about obstructing piles of drift and their being shaped into drumlins rather than their obliteration by erosion. It might also induce localized deposition in piles or ridges which would later be shaped and might be added to by the plastering on of drift. Computations based on the ice stream forming the second set of drumlins show the radiation to have been even more marked than in the first case, with corresponding greater crowding forward of the faster moving ice in the rear and more marked development of drumlins. Comparison with segments of the glacier which had equal initial widths but did not form drumlins shows that in the latter there was very moderate radiation and that, unless the ice in the rear was moving more slowly than that in front, there was a decrease in the volume of the stream as it advanced, as opposed to the increase in volume of the drumlin-forming stream. With the radiation fully accounted for by the ice under its own weight and with no forward crowding of the ice in mass there would be absence of lateral stress and of the tendency to longitudinal crevassing, and this may explain the absence of drumlins. Other factors than radiation are probably involved.

Structure.—The material of which the drumlins of the Grand Traverse area are composed is in large part a reddish till. This is especially true of the drumlins in the region of least relief and especially in the district shown in figure 2, between the north part of Torchlight Lake and the south arm of Pine Lake, where the drumlins are the most numerous and best formed of any in this field. Southeastward toward the moraine a change takes place from clayey to looser-textured material, and the drumlins on the extreme southeastern outskirts of the field are generally very loose textured. This change in texture is a natural result of an approach to the edge of the ice, for more or less fine material is carried away from the ice border by the waters discharging from the border, thus leaving the coarser material to be deposited in the moraines and other deposits made near the edge of the ice. Pressure is also markedly less near the edge than at several miles back under the ice, and where drumlin forming was going on this is likely to have been a potent factor in determining texture and compactness of the material.

BURIED LACUSTRINE (?) CLAYS OF GRAND TRAVERSE REGION.

Distribution.—Beneath the latest till deposits of the eastern coast of Lake Michigan from the vicinity of Frankfort northeastward nearly to the Straits of Mackinac there are frequent exposures of a clay which is nearly free from pebbles and which appears to have been deposited in water. In some of the exposures the clay is distinctly laminated and is evidently water deposited. In other exposures it was difficult to discover bedding planes, yet the absence or extreme scarcity of pebbly material renders the clay a doubtful glacial product. In a few places there are sandy partings between the layers of clay, and in such places the deposition in water is scarcely to be questioned. These clay deposits are present in the abrupt bluff-like borders of some of the deep valleys or valley-like lowlands which traverse this region. These lowlands ordinarily contain a great depth of loose sand, and it is not known whether this sand is underlain by the clay.

The altitude which the clay reaches beneath the crests of the ridges is difficult to determine. Exposures on the slopes of the ridges, by which it has chiefly been discovered, show it to be present south of Central Lake and southeast of Pine Lake in the vicinity of Boyne Falls up to an altitude about 300 feet above Lake Michigan, or 880 feet above sea level. West of Bellaire and near the northern end of the peninsula in eastern Emmet and western Cheboygan counties it was noted about 850 feet above sea level. Between Torchlight Lake and Grand Traverse Bay and on the peninsula between the arms of Grand Traverse Bay it is found up to a height of 800 feet or more. In the vicinity of Frankfort and northeastward past Crystal Lake and Platte River the highest exposures are between 680 and 740 feet above tide. Several exposures were noted in the vicinity of Benzonia. Exposures are good in Frankfort along the shore of Lake Michigan and also in excavations near the courthouse.

Structure and characteristics.—This laminated clay varies considerably in color In the vicinity of Frankfort, north of Pine Lake and northeast of Little Traverse Bay, it is red or pink. Along the east side of Grand Traverse Bay and near Central Lake on the west side of the west arm of Intermediate Lake much of it is drab or blue. The pink color seems likely to be due to the accession of ferruginous material from the formations in the northern peninsula, just as in the overlying till. The drab or blue is the ordinary color presented by deposits that have received no special contribution of red ferruginous material.

This clay is generally very calcareous, whatever its color. Much of it shows calcareous nodules and tubes on the face of the exposures. The deposit appears, therefore, to have received such a fine flour as is produced by the grinding of limestone formations by an ice sheet.

The thickness of the deposit differs widely, ranging from a few feet to 100 feet and possibly much more. The record of the boring at Elk Rapids suggests its presence to a great depth below the level of Lake Michigan, and exposures a few miles northeast of that village show its presence more than 200 feet above the lake.

Origin.—Much uncertainty exists as to the origin of this clay. Its range in altitude and its possible thickness are greater than seem easily attributable to ordinary lake action, and yet such may be the method of its deposition. Possibly before the ice made its final recession from this region the northern end of the southern peninsula of Michigan was low enough for the lake waters to cover all the places in which the clay has been found, although some of these are 300 feet above present lake level and about 200 feet above neighboring portions of the Algonquin beach, the beach of the first glacial lake that succeeded the final recession of the ice. Since Algonquin time there has been an uplift of only about 100 feet in the region bordering Little Traverse Bay, but there may have been a much greater pre-Algonquin uplift. The pre-Algonquin uplift, as shown in the tilting of the Arkona, Whittlesey, and Warren beaches, seems sufficient to support the view that if free

from ice in Lake Arkona time the region in which these buried silts are present would have been covered by lake waters to about the extent which these silt deposits reach.

The deposition of the silt may prove, however, to have been not in an open lake of broad extent, such as the glacial Lake Algonquin, but in narrow strips of water between lobes of ice that occupied the great valley-like lowlands now occupied by the arms of Grand Traverse Bay, Pine Lake, Torchlight Lake, and lesser lakes of the Grand Traverse region. As noted above, the deposit is found in the narrow strips of upland between these basins and is not found on the immediate floor of most of the great valleys. Possibly it is not present beneath these valleys, if the ice lobes were occupying the valleys during the deposition of the clay. Buried as this deposit is beneath thick deposits of till so that it is exposed in very few places, there is necessarily such a dearth of data concerning it that its origin can not be cleared up at the present writing.

The time of its deposition compared with the overlying till is also a matter of uncertainty. It is not known whether it is contemporaneous with the ice occupancy of the valley-like depressions, or whether it was deposited in a time corresponding to Lake Arkona between the recession of the ice and the readvance just discussed, or whether it is an interglacial deposit laid down before the Wisconsin stage of glaciation.

On the supposition of its being a pre-Wisconsin interglacial deposit it would naturally be interpreted as a mere remnant of the original deposit with great gaps along the line of the valleys made either by the pushing of the ice into these valleys or by ordinary stream action in interglacial times, or to a combination of the two processes.

On the supposition of deposition during an ice recession within the Wisconsin stage there would be less chance for ordinary stream erosion, and the great removal of material along the valleys would be chiefly referable to the action of the readvancing ice.

On the supposition of contemporaneous deposition with ice lobes occupying the valleys the deposit may now have about its original extent. On this interpretation the deposition of the clay may have been during the waning of the ice prior to the last readvance. It may have taken place, however, during a possible readvance in which the ice protruded into the great valleys before covering the upland. This would be likely to cause a heavy silt deposition, not only from the edges of the advancing lobes but from the broad field of ice which was about to encroach upon the upland.

On the whole the distribution and character of the deposits and especially the freshness of their appearance are thought to favor their close connection with glacial agencies either during the waning or the readvance of the ice in the later part of the Wisconsin stage of glaciation.

CHAPTER XII.
OUTLINE OF GLACIAL AND POSTGLACIAL HISTORY OF THE GREAT LAKES REGION.

By FRANK B. TAYLOR.

The Great Laurentian Lakes, or the Great Lakes, as they are commonly styled, are a group of valleys which have been turned into lakes. Geologically speaking, the lakes themselves are new and youthful forms, although the valleys in which they lie are much older.

PREGLACIAL HISTORY OF THE GREAT LAKES BASINS.

STAGES OF DEVELOPMENT.

The basins of the Great Lakes were once valleys with free drainage and no lakes, like the Ohio Valley of to-day. The events which changed them into water-filled basins were apparently associated with the glacial epoch and are therefore of relatively recent date. It is the later part of the Great Lakes history, comprising the glacial and postglacial stages, that has most engaged the attention of students, because the facts relating to that part are the newest and most numerous. But in any comprehensive view the fact should not be overlooked that the Great Lakes, or rather the basins in which they lie, had a long and complicated history before the glacial epoch and also a complex interglacial history. Only the main outlines of the earlier epochs are known at the present time, and it will here suffice to enumerate them briefly.

The preglacial history of the Great Lakes is the geologic history of the region. For convenience it may be divided into three stages, each dominantly though not exclusively characterized by a particular phase of development. The first was the stage of sedimentation or Paleozoic strata building—the constructional stage; the second was the epoch of land elevation, causing increase of altitude and starting erosion—the stage of emergence; and the third was the stage of erosion or valley making—the destructional stage. These three stages are not sharply and completely marked off from each other, although they may appear to be so in some parts of the Great Lakes area. For example, in the northwestern part uplifts producing emergence of land areas occurred while in much of the region of the lakes farther east sedimentation was going on uninterruptedly. Whatever land was raised above the sea was attacked by erosion. Thus, to some extent, sedimentation, elevation, and erosion were all going on at one and the same time. But the successive dominance of the three processes distinguishes fairly well the three phases of development.

STAGE OF CONSTRUCTION.

It is well known that the basins of the Great Lakes lie chiefly in depressions that were formerly filled and completely occupied by Paleozoic strata. While these strata were being laid down the whole region, except perhaps part of the Archean area south of Lake Superior and some parts of the plateau north of the Great Lakes, was under the sea. The rocks that filled these basins have very different characters in different beds. There are conglomerates and sandstones, shales and limestones, and in some places igneous rocks. Each of these classes of rocks has many varieties with more or less variation in hardness and chemical properties, and these qualities exercised an important influence on the rate and manner of disintegration under the forces of erosion. The formation of the Great Lakes basins has thus been dependent to a large degree on the character of the strata out of which they have been excavated—on their relative hardness, thickness, and arrangement.

This was the constructional period in which nature was getting ready for the subsequent making of the lake basins.

STAGE OF EMERGENCE.

The lake basins did not begin to be made until another great event in geologic history, involving a great change in the relative altitude of the land and sea, had taken place. Beginning at the close of the Paleozoic era great earth, movements affected all of the eastern part of North America, including the whole of the Great Lakes region, lifting the land now occupied by the lakes to an altitude estimated by some to be 2,000 or 3,000 feet higher than its present altitude. This was the time of the uplifting and folding of the Appalachian Mountains. The process probably occupied some thousands of years, but in a geologic sense its duration was short.

There is evidence also of some earlier movements of less extent that affected the region of Lake Superior and especially the northern part of Lake Huron, and that probably produced small land surfaces.

STAGE OF DESTRUCTION.

The forces of subaerial and stream erosion attacked the surface of the land as fast as it was raised above the level of the sea, and the sea itself, with its waves and tides and currents, attacked the new shores. Rain and frost, wind and sunshine, and the agents of chemical decomposition attacked every part of the land surface. Most effective of all was the water that gathered into flowing streams. All of these, great and small, did their share of work in tearing down and sculpturing the new land, earning valleys, hills, and mountains out of the elevated mass. Each worked with an efficiency dependent upon its volume, the rate of its descent, the character and quantity of the sediment it carried, and on other factors. The first shapes of the newly emerged land determined the first drainage systems, but as the work of erosion went on, the effects produced were greatly influenced by the variously resistant characters of the rocks and their relative position and arrangement.

The strata out of which the lake basins were later excavated were laid down for the most part not along the shores of that ancient time but at some distance offshore, so that the sediments received were mainly of fine texture, mud which afterward became shale and limy ooze which afterward became limestone. Conglomerates and sandstones indicating shore or shallow near-shore conditions occur, but are not common. Limestone does not rank as hard in the mineral scale, but relatively to the shales some of it is hard and resistant, especially where it occurs in massive form and in great thickness. In the building of the strata it happened that a group (Niagara) of beds whose arrangement and relative hardness predisposed them to unequal erosion and to the formation of valleys bounded by great escarpments was laid down from central New York to northern Michigan. The limestone of this group, a massive bed of the hardest quality, 150 to 200 feet thick, is underlain by several hundred feet of the Clinton and Medina formations of shales and sandstones—chiefly shales—and thin layers of limestone much softer than the overlying limestone. It is overlain by 200 to 300 feet of the very soft, marly, salt-bearing beds composing the Salina formation. The selective processes of erosion led the streams to attack the softer strata and to wear them away, leaving the harder limestone of the Niagara group to form the great escarpment which now stretches from New York to Wisconsin. Extensive valleys were eroded in the soft underlying rocks, undermining the limestone and driving it back. Other valleys were excavated in the soft overlying Salina formation.

Thus Lake Ontario, Georgian Bay, the northern channel of Lake Huron, and Green Bay were excavated out of the soft rock below the limestone of the Niagara group; and Lake Erie, the main body of Lake Huron, and all of Lake Michigan were excavated out of the soft strata above the limestone. Lake Superior appears to be somewhat exceptional. It is thought to be largely an original rock basin, or perhaps a syncline out of which soft rocks, probably in the main those below the limestone, have been eroded.

Thus, the shape and size and arrangement of the lake valleys were primarily dependent on the geologic structure—on the relative position and thickness of the soft beds and the distribution of their exposed parts. Where the soft beds were exposed to effective stream erosion they were removed more rapidly than the harder rocks and thus became the main valleys of the region.

In the present attitude of the land the Paleozoic strata dip distinctly but gently south in the basin of Lake Ontario; south in the eastern part and southwest and west in the western part of the basin of Lake Erie; southwest in the main part and south in the northwestern part of the basin of Lake Huron; south in the northeastern part and east in the southern part of the basin of Lake Michigan, and south in the peninsula east

of Marquette; steeply north in the western part and variously in other parts of the basin of Lake Superior.

That these valleys were going through the process of development by erosion during practically all the time from the close of the Paleozoic to the beginning of the glacial epoch seems not improbable. Indeed, the time must have been very long to have permitted the making of such extensive valleys by so slow a process. It might be thought that some movement of elevation or tilting had turned these old valleys into lake basins long before the time of the ice epoch, but no certain evidence indicating such a change has been found. Up to or nearly to the beginning of the ice epoch the valleys appear to have had complete drainage by rivers and to have held no lakes. Although the whole region was probably reduced to a peneplain more than once in the long time of preglaeial erosion, it appears to have stood at a relatively high altitude above sea level toward the close of that time. This is indicated by the deeper lake basins, by the submarine valleys of the St. Lawrence, the Hudson, and other rivers.

DIFFERENTIAL UPLIFT.

Some time before the beginning or possibly in the earlier part of the ice epoch, the northern lands were uplifted in such a way as to warp or tilt the region of these great valleys. The lands in the north were uplifted more than those in the south, and as the outflow of most of these valleys was northerly, their lower courses were elevated more than their headward parts, and they became water-filled basins or lakes. It is not known with certainty when the first important tilting took place. If the great period of diastrophism, which began in late Cretaceous time and reached a climax in the middle or later part of the Tertiary, was characterized by a southwestward creeping of the entire crustal sheet of the continent, as certain features seem to suggest, it may well be that the principal part of the warping which turned the open valleys into lakes occurred at that time and was the result of that movement. At present, however, the facts bearing upon this question are too few to warrant more than the briefest mention.

GLACIAL HISTORY OF THE GREAT LAKES BASINS.

EARLY STAGES.

The glacial epoch as a whole has been found to be made up of at least four distinct stages of glaciation separated by intervening warm periods when the ice sheet either shrank to relatively small proportions or disappeared altogether. The last ice sheet deposited what is known as the Wisconsin drift. There is abundant evidence, however, that the lake basins existed substantially as they are to-day during at least one of the earlier stages of glaciation. In the southeastern and central parts of the southern peninsula of Michigan there is a great body of older drift underlying the drift of the Wisconsin stage, and in the northern part of the same peninsula there are thick deposits of lake clays, which were deposited in the basin of Lake Michigan before the last advance of the last ice sheet, for they are overlain by drumlins of Wisconsin age. (See pp. 314-315.) Possibly they were deposited before the Wisconsin glaciation. The position and relation of these beds indicate that this part of the Lake Michigan basin was then in all respects the same as it is to-day, except that the water stood relatively somewhat higher upon the land; and this seems to indicate that if the lake had a northward outlet then as now, the northern part of the basin stood relatively lower than now, for in its present attitude it lacks only 8 feet of overflowing at its southern end. It seems certain that the depressions which constitute the lake basins were involved in each one of the several glacial stages; and yet all the basins, except perhaps that of Lake Superior, retain very distinct characters which belong to stream-eroded valleys. Indeed, except for the drift deposits and the effects produced by tilting, they may almost be said to show no other characters. All the changes produced by the several glacial invasions have not destroyed these characters nor obliterated them to any great extent. In fact, when the last ice sheet crept from the north down into the lake basins it appears to have found them in almost every detail the same as they are to-day.

No doubt the events of the lake history which occurred during the advancing phase of the last ice sheet as well as in the earlier glacial stages are matters which would be of great interest and importance if they were accessible; but they seem destined to remain in obscurity, because the record made by the ice at the climax of each minor movement of advance was continually being overridden and obliterated by later and more energetic readvances; and further, in the region of the Great Lakes the drift sheets of the older glacial stages were almost entirely overridden by the later ones.

GREAT LAKES DURING AND AFTER THE RETREAT OF THE LAST ICE SHEET.

COMPLEXITIES OF THE HISTORY.

The retreat of the ice in the last or Wisconsin stage of glaciation marks the beginning of that later phase of the lake history whose records are so clearly and completely preserved in the present surface deposits. This part of the history is spread like an open book upon the surface of the lake region. An immense body of facts bearing upon it and giving a fairly full knowledge of its details has already been gathered, and continued exploration will afford many more.

This part of the lake history has its own complexities, arising from several causes: (1) The oscillating manner of the retreat of the ice border, which was accompanied by periodic minor movements of retreat and readvance; (2) the irregularities of topography which characterize the lake region; (3) the variation in the direction of the general retreat of the ice limit across the lake basins;

and (4) the differential elevation of the land during and after the ice occupation, the maximum elevation occurring in the north and producing several changes of outlet.

The combined effect of these and other less important factors produced a complex history, not only as expressed by the distribution and relations of the various drift forms, but also by the remarkable effects of the ice sheet on the associated drainage. It determined the location of great rivers which flowed only temporarily from the ice or along its border and it caused remarkable shiftings of their courses. Its most noteworthy effect, however, was the production of a complex succession of shifting and changing lakes—enlarging, falling, shrinking, combining, dividing, and rising—of large extent and frequent changes of outlet, coming at last to the lakes as they are to-day. As investigation has inclined more and more to details and has covered an increasing area it has been found that the succession of changes involved in the later lake history is much more complex than was formerly supposed.

SHRINKAGE OF THE ICE SHEET INTO THE LAKE BASINS.

In one of its earlier stages (the Illinoian) the ice sheet covered the entire region of the Great Lakes, the only exception being the well-known Driftless Area which lies chiefly in western Wisconsin. This area is in the angle between Lake Michigan and Lake Superior, but does not comprise any part of the drainage basin of either one of them. As the ice sheet moved southward the lake basins naturally offered the easiest lines of flow and the high lands between the basins were areas of greater resistance and slower flow. But when the ice attained its maximum, reaching nearly to Cairo in Illinois, about 10 miles beyond Ohio River south of Cincinnati in Kentucky, and to Beaver Falls in Pennsylvania, the lake basins became relatively unimportant in their effect upon the ice movement, for at that time the ice overwhelmed them all, including even the high lands between them. As it retreated, however, the relative importance of the lake basins in controlling the ice flow increased rapidly and by the time the ice front had withdrawn to the most southerly points of the watershed of the lake basins it had taken on lobate forms of a most pronounced type. In the latest or Wisconsin stage of glaciation the farthest extension of the ice did not reach so far south in the region west of central Ohio as it had before. In Illinois it reached only about halfway from the shore of Lake Michigan to Mississippi and Ohio rivers. As the ice drew back, each lake basin, at the time of most pronounced lobation, had its ice lobe, which conformed to the outlines of its southern part with remarkable fidelity. The moraines laid down along the margin of the lobes at this stage are roughly concentric with the basins and nearly parallel with their southern shores.

OSCILLATIONS OF THE ICE FRONT.

The periodic oscillations in the retreat of the Wisconsin ice sheet introduced a peculiar complexity into the lake history. It has been shown above that the stronger or principal moraines formed at the culmination of a readvance mark relatively long intervals of time—several hundreds of years, perhaps more than a thousand. The readvance to the moraine covered a very considerable distance, certainly in some cases 25 to 50 miles and perhaps twice as much. The long intervals of time between a moraine that precedes and one that follows such an oscillation accounts perhaps to some extent for the commonly observed discordant relation between them.

Important oscillatory variations in the retreat of the ice produced a corresponding effect on the lake history, for after lakes were lowered by a retreat of the ice the readvance was likely to close their outlets and raise their waters to higher levels. Three times, certainly, and perhaps four or five times such a change affected the waters of the Huron-Erie-Ontario basin. During several oscillations the ice front stood in critical relations to the land barriers that held up the lakes and relatively slight changes in position opened or closed outlets and changed the level of the lake waters.

In view of the apparent character of the glacial oscillations it seems necessary to take account also of the halts of the ice front at the back steps or climaxes of retreat. These probably affected the lakes as greatly and lasted as long as did the halts on the moraines which mark the climaxes of advance. In one place at least there is remarkably clear and complete proof of the long duration of a particular lake stage (Arkona) which existed during the pause at a back step or climax of retreat. The changes of the lakes during the retreat of the ice front across the Huron-Erie-Ontario basin are the most complicated now known and form the central theme of the discussion that follows.

THE FIRST LAKES.

As soon as the ice front withdrew to the north side of the southern watershed of the Great Lakes small ice-dammed lakes began to be formed. In Ohio a number of such lakes appeared along the north side of the divide south of Lake Erie. It seems a necessary inference that in consequence of the oscillations of the ice many of these earliest small lakes were formed at the extreme position of retreat and were overridden and obliterated by the next readvance. Indeed, some of them may have been formed and overwhelmed two or three times before the larger lakes became permanently established. There is some evidence of this sort of development at Fort Wayne, Ind.

The earliest small lakes discharged at first southward independently through several gaps in the divide; a little later they fell to lower levels and discharged westward to a lower gap; and finally they discharged into the first small, narrow representative of glacial Lake Maumee. Mr. Leverett has already described these earliest lakes in Ohio;[1] he has also described others of some-

[1]Leverett, Frank, Glacial formations and drainage features of the Erie and Ohio basins: Mon. U. S. Geol. Survey, vol. 41, 1902, pp. 610-611.

what similar origin that were formed along the east side of the Lake Michigan basin (pp. 225-227). Winchell has described a series of small lakes that preceded the larger lakes in the western end of the Lake Superior basin.[1]

When the ice front had retreated to a position a little east of the watershed at Fort Wayne, Ind., a long, narrow, crescent-shaped lake, known as glacial Lake Maumee, was formed between the ice barrier and the land. Similarly, when the ice front had withdrawn a few miles north of the watershed at the south end of Lake Michigan and was building the later members of the Lake Border morainic system, another long, slender, crescent-shaped lake was formed between the ice barrier and the land; this was the beginning or first stage of glacial Lake Chicago. If the moraines have been rightly interpreted Lake Maumee came into existence shortly before Lake Chicago.

A third lake of the same kind (Lake Duluth) was formed in the same way at the western end of the Lake Superior basin, when the Lake Superior ice lobe finally shrank within the line of the watershed west of Duluth. Mr. Leverett's work in Minnesota in 1910 and 1911 indicates that the beginning of this lake was considerably later than that of the first lakes at Fort Wayne and Chicago. He makes a tentative correlation of the Port Huron morainic system (formed at the time of Lake Whittlesey) with a moraine which encircles the west end of Lake Superior and antedates Lake Duluth, thus making Lake Duluth younger than Lake Whittlesey.

Two small lakes, formed probably a little later than Lake Chicago, gathered in front of the Green Bay lobe of the ice sheet in Wisconsin and discharged first southward to Rock River and then southwestward to Wisconsin River. These lakes, however, had a relatively short independent existence, for they soon combined into one lake and when the retreating ice opened a passage eastward to the basin of Lake Michigan their waters merged with those of Lake Chicago.

From these four relatively small beginnings there grew a series of glacial lakes, the like of which for size and complicated history is not known in any other part of the world. The total area covered by their waters from first to last was much greater than the entire area of the present Great Lakes, but the whole area was not covered at any one time. Only one glacial lake of larger size is known to have existed; this is Lake Agassiz, which overspread northwestern Minnesota, northeastern North Dakota, and a great area in Manitoba and Saskatchewan. But the history of Lake Agassiz appears to have been very simple in comparison, for the basin which it occupied was simpler in form and its relations to the ice sheet were less complicated.

GLACIAL LAKES IN THE HURON-ERIE BASIN.

COMPLEXITIES OF DEVELOPMENT.

The lowland which stretches from Lake Huron southward to Lake Erie was abandoned by the ice sheet in the middle stages of the development of the glacial lakes, but continued to be covered by the lake waters, so that the waters in the southern part of the Lake Huron basin were joined with those in the basin of Lake Erie as one, and at a later stage this extensive lake was further expanded so as to cover the western part of the basin of Lake Ontario.

The succession of lakes in this basin is more complex than in any other part of the lake region. These complexities grew out of several different causes: (1) The configuration of the chief elements of relief—deeper basins separating higher lands and ridges, and the position and varying altitude of the watershed south of the lakes; (2) the general direction of the glacial retreat and the trend of the ice front with reference to these features; (3) the oscillations of the ice front during retreat, comprising not only periodic movements of retreat and halt, but also alternating movements of readvance over relatively wide intervals of space; and (4) (especially in the later stages) the tilting or northward differential elevation of the land. The readvances of the ice introduced the greatest element of complexity and produced their effects chiefly by closing outlets and raising the level of the waters. This occurred repeatedly shortly after the waters had been lowered by a movement of retreat.

[1]Winchell, N. H., Bull. Geol. Soc. America, vol. 12, 1900, pp. 121-122.

LAKE MAUMEE.

Lake Maumee had at least three distinct stages and possibly more. Those clearly determined are as follows:

Highest stage.—As the ice front retreated eastward from the moraine at Fort Wayne, Ind., it uncovered what is now the upper Maumee Valley, but continued to occupy the present lower part of that valley and therefore to obstruct its normal northeastward drainage. Consequently, Lake Maumee came into existence between the moraine and the ice front. As the ice retreated the lake widened eastward and long arms of water extended eastward into Ohio and northeastward into Michigan between the shrinking ice lobe and the land.

How far the ice retreated is not certain. The next strong moraine in the Maumee Valley is at Defiance, Ohio, but in view of the periodicity and the wide space covered by the readvances, it may be regarded as certain that the retreating ice front did not stop at Defiance but receded to a point probably not less than 25 or 30 miles east of that place and there halted for a considerable time before readvancing. There were also minor oscillations during both of these movements.

The waters of the lake rose until they found an outlet westward through the present site of Fort Wayne and thence southwestward to Wabash River at Huntington and ultimately to Ohio and Mississippi rivers and the Gulf of Mexico. The time of the opening of this outlet is not certain. Possibly the lake stood at its highest level and discharged at Fort Wayne during the climax of its retreat,

although this is doubtful. But during its readvance to Defiance and its » pause at the Defiance moraine it certainly overflowed at Fort Wayne. The first stage ended only when the Fort Wayne outlet was finally abandoned.

Lowest stage.—When the ice front retreated from the Defiance moraine it fell back a long step to the eastward and opened a lower outlet somewhere near Imlay, in Lapeer County, Mich. Below the highest or first beach of Lake Maumee there are two others which evidently belong to this lake. One, the middle beach of Lake Maumee, is 15 to 25 feet below the first beach and is a normal wave-made shore line of moderate strength. The other or lowest beach, which is about 20 feet below the middle beach, is faint and fragmentary and has been greatly modified by later submergence. These two lower beaches have a curious relation; the lowest beach was made next after the highest and then the level of the lake was raised and the middle beach was made at a higher level. The storm waves which made the middle beach swept over the gravelly ridges of the earlier one below, which lay in 20 feet of water, and almost destroyed them. Hence, when the lowest beach was being made the lake was in the second stage. The location of the outlet for this stage is not known with certainty; it may have passed northward a few miles east of Imlay and thence westward across Tuscola County, but if so it was overridden and obliterated by a readvance of the ice. In its horizontal part the lowest beach is 760 feet above sea level.

Middle stage.—When the ice front readvanced, it closed the outlet for the lowest stage and moved westward to a position close along the east side of the great Imlay outlet channel, which passes northward just east of Imlay. This channel shows evidence of having been crowded westward by the ice as it was building the moraine along its east side. At this stage Lake Maumee was barely too low to overflow at Fort Wayne.

When the ice retreated from this last position, it opened a temporary outlet across Tuscola County, but did not open a permanent new outlet until it had retreated many miles to the north toward the northern part of the "thumb." The opening then made, however, allowed the lake waters to fall suddenly to a much lower level.

In the middle or latest stage Lake Maumee reached its greatest extent, stretching from Fort Wayne, Ind., northward to a point several miles north of Imlay, Mich., and eastward nearly to Girard, Pa. The front of the contemporary ice lobes probably extended from the vicinity of Detroit into Lake Erie, 40 or 50 miles east of Toledo. At its front the ice was therefore standing in water 150 to 200 feet deep.

LAKE SAGINAW.

During the later stages of Lake Maumee a small lake appeared in the Saginaw Valley in front of the Saginaw ice lobe and received the drainage of the Imlay outlet river. At first it was narrow and crescent shaped, but it grew somewhat larger and wider before the end of Lake Maumee. Its outlet was westward through the Grand River channel for a few miles west of Grand Rapids and thence south along the ice front to Lake Chicago. Lake Saginaw was merged with Lake Arkona, restored to independence during Lake Whittlesey, and merged with Lake Warren before its final extinction by the abandonment of its outlet.

While it existed as an independent body, Lake Saginaw was limited to the Saginaw Valley, which is a part of the basin of Lake Huron. It was also a part of Lake Wayne and later of Lake Lundy, but the outlet was then eastward to the Mohawk near Syracuse, N. Y.

GLACIAL LAKES IN THE HURON-ERIE-ONTARIO BASIN.

LAKE ARKONA.[1]

The next important step in the ice retreat changed still more profoundly the condition of the glacial lakes. (See fig. 6, p. 370.) The ice withdrew altogether from the "thumb" of Michigan, allowing the entire sweep of lake waters to the eastward to fall to the level of Lake Saginaw and to merge with that lake. Lake Saginaw had at the same time expanded largely northeastward, and a strait several miles wide had opened past the end of the "thumb." The enlarged lake, which is called Lake Arkona, stretched from the vicinity of Gladwin, Mich., to at least 40 or 50 miles east of Buffalo, N. Y., and covered a considerable part of southern Ontario. Its outlet was westward through the Grand River channel. Its altitude above sea level was at first 710 feet, but by cutting down of the outlet it became reduced to 694 feet. West and northwest of Port Huron are three beach ridges formed by this lake, known as the Arkona beaches.

LAKE WHITTLESEY.

After the formation of the Arkona beaches the ice front made a pronounced readvance southward up the slope of the "thumb" to Ubly, building the Port Huron morainic system, cutting off the Saginaw Valley, and restoring Lake Saginaw to independence. The advance had no effect on the waters of Lake Saginaw, but it raised those of the lake area east of the " thumb " by about 44 feet, forming a new lake, known as Lake Whittlesey, whose surface stood about 28 feet above the highest Arkona beach ridge in the region northwest of Port Huron and 44 feet above the lowest.

On the northern part of the "thumb" the Arkona beaches were overridden by the ice and a considerable extent of them was buried beneath the terminal moraine or beneath outwash. In the southern part of the Black River valley northwest of Port Huron they were not overridden nor buried but were submerged. Within the valley they are strongly developed gravelly beach ridges and show no modification due to submergence. Outside, on the south, however, they were almost entirely washed away by the storm waves of Lake Whittlesey and in many places are traceable only with much difficulty. Although they were 28 to 44 feet under

the water, the storm waves swept their gravels rapidly up the slope and built them into the Whittlesey beach.

The Whittlesey beach has characters which indicate that it was pushed up the slope as it was made and that it was made rapidly, for it stands very high above the adjacent land and is peculiarly independent of topography, crossing valleys of moderate depth in a direct line like a railroad embankment.

LAKE WAYNE.

Below the Arkona beaches lies the Warren beach and next lower the Wayne beach. But the Wayne, like the Arkona and middle Maumee beaches, shows evidence of having been submerged and modified while the Warren beach was being formed above it at the margin of the raised lake. The lake level appears to have dropped abruptly 80 or 85 feet from the Whittlesey beach to the Wayne beach, the drop being of course due to a recession in the border of the ice, which permitted the reunion of Lake Saginaw with the larger lake to the east and caused a further lowering of these united waters by about 40 feet.

[1]The lakes preceding Lake Arkona were confined to the Huron-Erie basin and did not include any part of the basin of Lake Ontario. Lake Whittlesey, following Lake Arkona, was also limited to the Huron-Erie basin.

The Wayne beach is generally faint, and on the "thumb," where it is gravelly, it shows distinct evidence of submergence and modification after it was made. Except on the "thumb," it is generally sandy and without marked characteristics. In the Saginaw Valley it lies barely below the head of the channel which had served as the outlet of Lake Saginaw. It is quite certain that it had no outlet toward the northwest through the Straits of Mackinac, and it probably drained eastward to the Mohawk, passing along the ice margin, where it rested on the hills south of Syracuse, N. Y.

LAKE WARREN.

When the ice front readvanced, covering part of the ground previously vacated, it closed the outlet which had recently been opened near Syracuse and raised the lake to the level of the Warren beach. In the Saginaw Valley the Warren beach passes 20 to 25 feet above the col at the head of the Grand River outlet channel, here extremely flat and much covered with dunes.

In Michigan the Warren beach extends up to the vicinity of Au Sable River north of Saginaw Bay but has not been identified farther. In New York it has been traced for some distance east of Genesee River. Its limits in Ontario have not been determined. While the Warren beach was being made the Wayne beach was being destroyed, and the Warren beach, like the Whittlesey, shows in some places but not so strongly the characters which indicate rapid accumulation.

In the later stages of the lake waters, from Lake Arkona on, the area covered by the lakes included not only the basin of Lake Erie but parts of those of Lakes Huron and Ontario also. From New York, Fairchild reports evidences of a readvance and raising of lake level later than the one which affected Lake Warren. That movement, however, appears to have been confined to the Lake Ontario basin and had no effect upon the waters of the Huron-Erie basin.

The beaches of all the foregoing lakes are horizontal in the southern part of the region they cover, but in the northern part they rise slightly toward the north-northeast. The area of horizontality lies southwest of a line passing about 5 miles north of Birmingham, Mich., to Ashtabula, Ohio. This seems to have been a sort of hinge line for the earlier deforming movements. North of it all the beaches rise gradually in a direction about north-northeast, but the earlier ones begin to rise before the later ones, as if the deforming force had migrated slowly northward, following the retreat of the ice front.

LAKE LUNDY (LAKE DANA, LAKE ELKTON).

When the waters fell from Lake Warren they halted first at the Grassmere beach and later at the Lundy (Dana, Elkton) beach, before they finally separated from the waters of the Lake Erie basin. The outlet at both stages was probably near Syracuse, N. Y., but connection with that region has not been established by continuous tracing. It was probably during the time of Lake Lundy and perhaps also during that of Lake Wayne that the great cataracts (allied to Niagara) existed in the hills southeast of Syracuse, N. Y.

The two beaches have only moderate strength. On the "thumb" they show the most remarkable example of northward splitting that has been found. The outer part of the "thumb" was being elevated while they were being made, and each beach consequently splits from a single strand to four or five separate weaker strands covering a vertical interval of 25 to 30 feet. In the area of horizontality the Grassmere has an altitude of 640 feet and the Lundy (Dana, Elkton) of about 620 feet. Both are generally gravelly on the "thumb" but are sandy elsewhere. They have been studied very little east of Michigan, probably in part because they are weak. They mark the transition to Lake Algonquin, the largest of the glacial lakes in the Great Lakes region.

GLACIAL LAKES IN THE LAKE ONTARIO BASIN.

EARLY LAKES.

When the Lake Ontario ice lobe had retreated far enough to uncover the southern parts of the valleys of the Finger Lakes in central New York, small lakes gathered, at first as separate bodies. With continued recession these lakes were lowered and combined in a complex series of changes that led finally to the later, larger lake that filled the whole basin of Lake Ontario. These changes have been set forth in considerable detail and illustrated by a series of maps by Fairchild.[1] The first local glacial lakes had independent outlets toward the south. The succession of lakes, as given by Fairchild, is as follows: Watkins, Newberry, Hall, Vanuxem, Second Vanuxem, Warren, Dana, Dawson, Iroquois.

LAKE NEWBERRY.

The first combination of the dozen or more small lakes in the Finger Lakes valleys into one lake has been called Lake Newberry. Its outlet was southward from Seneca Lake to Susquehanna River.

LAKE HALL.

At a slightly later stage of recession an outlet was opened westward to the glacial waters in the Lake Erie basin. The lake at this stage is known as Lake Hall.

LAKE VANUXEM.

At a slightly later stage a lower outlet was opened eastward to the Mohawk Valley, and this stage is known as Lake Vanuxem. After this there was for a time free drainage eastward, with only two low, small lakes, one in the Genesee Valley and one in the valley of Cayuga Lake. Later, however, on the readvance of the ice front, Lake Vanuxem was reestablished (Second Lake Vanuxem), after which the waters of the southern part of the Lake Ontario basin again merged with those in the Huron-Erie-Ontario basin.

LAKE DAWSON.

When the waters had fallen so as to separate those in Lake Erie from those of the Lake Ontario basin, an outlet was established eastward past Syracuse, N. Y. A number of oscillations of lake level, corresponding to slight retreats and readvances of the ice front, probably occurred. Toward the end of these oscillations the ice front, according to Fairchild, rested against the relatively high ground east of Rochester, forming a barrier across the Lake Ontario basin and dividing the waters into two bodies, Lake Dawson on the west and a smaller lake, draining from Lake Dawson and emptying into the Mohawk, on the east.

LAKE IROQUOIS.

When the waters of the Lake Ontario basin fell to the level of the pass at Rome, N. Y., they discharged eastward through the Mohawk Valley. This established Lake Iroquois, which endured for a relatively long time. The land, however, was uplifted around the north and east sides of this basin while the lake was discharging at Rome. This backed the water up on the south and west and caused it to fall away from the northern and eastern shores.

LAKE FRONTENAC.

When the retreating ice opened a passage eastward around the north side of the Adirondack Mountains to the basin of Lake Champlain, the lake level fell and the outlet at Rome was abandoned. At this stage the ice barrier or dam rested about on the Frontenac axis of the pre-Cambrian rocks and the lake may therefore be called Lake Frontenac.

[1]Fairchild, H. L., Glacial waters in central New York: Bull. New York State Mus. No. 127, 1909.

GILBERT GULF.

Finally the sea, which then stood relatively higher than now (523 feet higher near Covey Hill on the northern base of the Adirondacks),[1] entered and turned what had been a glacial lake into a marine gulf, known as Gilbert Gulf.

GLACIAL LAKES IN THE LAKE MICHIGAN BASIN.

LAKE CHICAGO.

While this complicated history was being enacted in the Huron-Erie-Ontario area, the glacial waters in the basin of Lake Michigan were also undergoing expansion. Here, however, the changes were extremely simple, for until the very last no critical ground affording a new outlet was encountered. The changes that occurred in Lake Chicago were due to erosion of its outlet or to changes in the volume of its discharge. From its first beginning as a narrow crescent-shaped lake at the extreme southern end of the Lake Michigan basin Lake Chicago had expanded northward as the ice receded until two-thirds or three-fourths of the basin was uncovered. In all probability the retreating ice front performed here the same series of oscillations, with strongly marked steps of retreat and readvance, that took place in the Huron-Erie basin. The evidence of these oscillations, however, are not generally so well marked, because critical changes were not produced by them; but some of the stronger moraines mark readvances that override beach ridges which had been made just previously.

The Port Huron morainic system skirts the north side of the high ground of the southern peninsula of Michigan and appears to be correlated in part with the morainic ridges which pass beneath Lake Michigan just south of Manistee. The Whitehall moraine of the Lake Michigan basin is considered to be a part of the complex Port Huron morainic system.

Studies by Alden,[2] under the direction of Chamberlin, on the west side of the Michigan basin, have developed evidence of a distinct readvance of the ice to Milwaukee characterized by a deposit of red till, and this probably correlates with the Whitehall moraine (p. 302). Later ridges of red till, which come down to the shore of Lake Michigan near Manitowoc and Two Rivers, Wis., also probably correlate with the Manistee moraine. This correlation is inferred not only because of similar position on opposite sides of the lobe and in reference to earlier moraines, but also because these later ridges do not appear to carry the Calumet and Glenwood beaches of Lake Chicago (see pp. 354, 355), which are present on the Whitehall moraine. Two lower beaches in the same area seem to have wider connections. The upper one is the Toleston beach, 24 or 25 feet above Lake Michigan, and the Nipissing beach, about 15 feet above the lake. The summit in the Chicago outlet in the south part of the city is only 8 feet above Lake Michigan, and is a broad, flat region much obstructed by low, sandy ridges. The Toleston beach passes over this broad divide at a level high enough to have permitted Lake Chicago to

discharge over it, even when it received the discharge of Lake Whittlesey or Lake Warren. Nevertheless, the Toleston beach seems to be continuous with the Algonquin beach, which traverses all of the upper three lake basins, and part of the overflow of Lake Algonquin may have been by way of Chicago for a time. The relation of the Chicago outlet to Lake Algonquin is still somewhat problematic.

When the ice lobe in the Lake Michigan basin retreated into the northern part of that basin it uncovered ground of critical interest on both sides. On the west side the glacial waters of the Lake Superior basin had been held up to a higher level than those of Lake Chicago, and when an opening occurred around the hills southeast of Marquette these waters drained southward along the western edge of the Green Bay lobe of the ice sheet and ultimately into Lake Chicago.

[1]Fairchild and Goldthwait, personal communications.

[2]Alden, W. C., personal communication.

Bordering the west shore of Lake Michigan and extending into the Green Bay-Lake Winnebago trough and the Fox and Wolf river valleys is an extensive deposit of red clay, partly laminated and partly pebbly and massive, which was described by Chamberlin.[1] Later study of this deposit by Alden,[2] under the direction of Chamberlin, shows that the larger part of this deposit, the massive pebbly clay, is a glacial till which was laid down during a readvance of the glacier in the Lake Michigan basin as far south as Milwaukee and of the Green Bay lobe in the Green Bay-Lake Winnebago trough to a point south of Fond du Lac, Wis. The ice also crowded westward in the Fox and Wolf river valleys. The red silt composing the laminated clay and the matrix of the massive pebbly clay is thought to have come from the Lake Superior region, being brought into the Green Bay and Lake Michigan basins by the opening of a southward outlet southeast of Marquette. The first opening of this outlet must have been at or near the climax of the ice retreat, immediately before the readvance to the first red till moraine. The phenomena indicate a readvance over a relatively wide interval, and it seems certain that if a lower outlet had been opened by the retreat it was closed again by the readvance, and that the level of the glacial waters in the western half of the Lake Superior basin was raised again to the level of some earlier and higher outlet. In fact, Mr. Leverett's studies have led him to the tentative interpretation that at the time of this readvance the ice completely occupied the western Superior basin, so that all the beaches of Lake Duluth are later.

On the east side, the retreating ice front finally reached the straits of Mackinac, where an opening allowed the waters of Lake Chicago to unite with those of the Lake Huron basin. Whether this merging of the waters in the Lake Michigan and Lake Huron basins occurred before or after the opening of the Trent Valley outlet in Ontario is not certainly known.

LAKES IN THE GREEN BAY BASIN.

Very little has been written concerning the glacial lakes in the Green Bay basin, and their extent has been as yet only partly worked out. Upham[3] published a paper in 1903 suggesting Jean Nicolet as the name for a lake that discharged from the Fox River drainage past Portage, Wis., to the Wisconsin Valley. Upham's paper was based on a brief visit to the outlet, and the existence of the lake was inferred partly from the presence of the outlet channel and partly from Chamberlin's description of the red clays in the Green Bay basin as lacustrine.[4] Alden's studies[2] have shown that the red clay was largely worked over and formed into morainal ridges and till sheets by a readvance of the ice, so that the limits of the red clay in the Green Bay basin mark a glacial instead of a lake border. Alden's studies have also shown that the lake history in this basin is somewhat different from that set forth by Upham. A lake, which discharged from the district south of Lake Winnebago southward past Horicon into Rock River, persisted until the ice which formed the moraines at the head of Lake Winnebago had receded far enough northward to open a passage westward from Oshkosh to the headwater part of Fox River. Then the discharge was shifted past Portage to the Wisconsin Valley. Later, when the melting of the ice cleared the Green Bay peninsula, the waters lowered to the Lake Winnebago level and to a lake in the Green Bay basin by discharging eastward into Lake Chicago. Similar events accompanied the preceding recession of the ice front and also, in reverse order, the readvance of the ice which formed the red till moraines.

GLACIAL LAKES IN THE LAKE SUPERIOR BASIN.

EARLY LAKES.

From the first small lakes at the extreme western end of the Lake Superior basin the glacial waters expanded as they did in the Lake Erie and Lake Michigan basins. In the earlier stages, while the lakes were small, slight changes in outlet and level occurred, the early stages having southward outlets directly or indirectly to the St. Croix Valley.

[1]Geology of Wisconsin, vol. 2, 1877, pp. 221-228.

[2]Alden, W. C., personal communication.

[3]Am. Geologist, vol. 32, 1903, pp. 105-115, 330-331.

[4]Geology of Wisconsin, vol. 2, 1877, pp. 221-228; Geologic Atlas of Wisconsin, Pl. II, 1881.

LAKE DULUTH.

Finally came Lake Duluth, with its outlet southward through the Brule and St. Croix valleys. Lake Duluth endured for a much longer time than the earlier lakes and its lower levels expanded to a lake of large size, forming beaches found even on the northern part of the Keweenaw Peninsula. Its outlet was cut down about 40 feet, lowering the level of the lake and causing the formation of later beaches below the highest.

Several lower beaches, which have been traced by Mr. Leverett (p. 431), seem to lie too low for waters discharging through the St. Croix outlet and hence may not belong to Lake Duluth. These suggest an outlet somewhere to the east and south around the hills south of Marquette, the exact place being not yet determined. These beaches are rather weak and suggest the possibility of submergence in consequence of a readvance of the ice.

GLACIAL LAKES IN THE SUPERIOR-MICHIGAN-HURON BASIN.

LAKE ALGONQUIN.

Stages of Lake Algonquin.—In the outline given above the succession of lakes in each of the upper three basins—those of Lakes Huron, Michigan, and Superior—were given down to the time when the glacial waters in all three were about to merge into one great lake. This larger body is called Lake Algonquin and its upper beach is one of the strongest and most persistent shore lines in the Great Lakes region. At its greatest extent this lake covered an area considerably larger than all three of the upper Great Lakes of the present time.

When the lake waters fell to lower levels from Lake Warren and Lake Lundy they uncovered for the first time the lowlands between Lakes Huron and Erie. This lowland divided the waters into two separate lakes and inaugurated the flow of St. Clair and Detroit rivers.

Lake Algonquin may be divided into four stages: (1) Early Lake Algonquin, confined to the south part of the Lake Huron basin; outlet at Port Huron. (2) Kirkfield stage, covered all of the upper lakes except the northern part of Georgian Bay and probably the northeastern part of Lake Superior; outlet at Kirkfield, Ontario; uplift in north begins. (3) Port Huron-Chicago stage; outlets at Chicago and Port Huron, but diminishing at Chicago and increasing at Port Huron; great uplifting, producing divergence of beaches northward; three groups of beaches, Upper Algonquin, Battlefield, and Fort Brady; most rapid uplift during Battlefield group. (4) Closing transition stage leading to Nipissing Great Lakes; outlet eastward to the Ottawa Valley.

Early Lake Algonquin.—For a relatively brief stage immediately following the time of Lake Lundy the waters in the south half of the Lake Huron basin formed an independent lake. This has been called Early Lake Algonquin. It was at the beginning of this stage that St. Clair and Detroit rivers first came into existence, and the outlet during this time was through these rivers to Lake Erie. The ice front then rested against the highlands which bounded the two sides of the southern half of Lake Huron, as shown by the moraines in both Michigan and Ontario. This stage, however, was relatively short, for the ice front stood so far north at its beginning that a slight additional retreat opened passages to the east and northwest where lower outlets were available—to the east to Georgian Bay and Trent Valley in Ontario and to the northwest to Lake Chicago. These two passages probably opened nearly at the same time. From the fact that no separate beach or outlet is known for this stage it might be thought that it is wholly hypothetical and its existence entirely uncertain. But, besides the local consequences of the relation of the ice sheet to the highlands, the early distributaries of the St. Clair and Detroit rivers seem inexplicable except as incidents of the transition from Lake Lundy to a lower stage with southward outlet corresponding to Early Lake Algonquin. And, further, the five short gorges made by Niagara River in the Niagara escarpment during its early flow show conclusively that the river then had a volume as large or perhaps larger than at present, and this it could not have had unless it received a large contribution of water to Lake Erie from the north. This was clearly before the opening of the Kirkfield outlet in Ontario. The discharge from Early Lake Algonquin was larger than might be expected, because this lake received a large affluent from the east, from the region of the Nottawasaga Valley and Lake Simcoe in Ontario, and also a large amount directly from the ice barrier.[1]

Kirkfield stage.—There is no reason to suppose that the Chicago outlet was at first low enough to take the whole discharge from Port Huron. On the other hand, the Trent Valley outlet at Kirkfield, Ontario, was surely low enough, and as soon as a way was opened to it the overflow went there and the level of the lake fell below the outlets at Port Huron and Chicago, for the character of the outlet channel at Kirkfield and below shows that it carried the full discharge of the upper lakes for a long time. Indeed, the principal or upper strand of the Algonquin group of beaches is remarkably strong and continuous not only in the southern parts of the basins but runs on unbroken in the same character far toward their northern sides. If it is lacking anywhere it can be only on the far northern sides of the basins, for it is strongly developed on the high ground north of Sault Ste. Marie, Ontario. Apparently during the making of the upper strand the lake was nowhere subject to deforming or warping influences and the outlet was at Kirkfield.

At length when the ice sheet had almost entirely disappeared from the lake basins a great movement of differential elevation began to affect the land. This movement embraced a vastly greater area than that of the Great Lakes, but within this area it affected the northern parts most. South of a line running through the middle of the “thumb” of Michigan and across the south arm of Lake Huron about S. 68° E. and also south of a line running westward across Lake Michigan from a point south of Frankfort the Algonquin beach was not affected at all by the uplift. This line was a sort of “hinge” line for the movement. Kirkfield at the head of the Trent Valley outlet was well within the region of strong uplifting, so that probably early in the movement it was raised to a position higher than the outlets at Port Huron and Chicago. The Kirkfield outlet was then abandoned and the discharge was shifted to Port Huron and Chicago. South of the isobase of Kirkfield the Algonquin beach of to-day is not the first beach made when the Kirkfield outlet carried the whole discharge, but is a transition beach made when two or probably three outlets were

active at once. This might be called the Algonquin transition or three-outlet beach, but the name Algonquin beach has generally been applied to the whole strand. The original Algonquin beach is now seen only in the region north of the Kirkfield isobase. While the Kirkfield outlet was active and carried the whole discharge, the isobase of that outlet served as a nodal line on which the water plane swung, the shores to the north of it being left dry and those to the south of it drowned.

In the region north of the hinge line uplifting and tilting progressed with increasing rapidity. The outlet at Kirkfield was raised altogether something more than 270 feet after its abandonment, for it now stands 295 feet above the level of Georgian Bay, and Lake Huron in the meantime has been lowered 25 feet by the erosion of its outlet at Port Huron. Farther north and northeast the amount of elevation was still greater.

Northward from the hinge line the beach for some distance rises gradually, but about on an isobase passing through Traverse City it begins to rise more rapidly and begins also to split into a vertically diverging series of subsidiary strands which are separated by wider and wider vertical intervals toward the north. This splitting of the strands toward the north shows that the land was being differentially elevated during the life of the lake. The different strands are not of the same strength nor are they equally spaced vertically, showing apparently that the uplifting movement was not steady in its progress, but was marked by a number of longer or shorter pauses.

[1]If the plan of naming the lake stages were strictly adhered to a separate name would be applied to this stage and the name Algonquin would not be used. This stage should be put under the head of "Glacial lakes in the Huron basin." But partly because there was at first a lack of complete proof of the existence of this stage and partly because the multiplication of names for lake stages seemed undesirable, the name Early Lake Algonquin was used and it has now appeared so many times in printed texts and on published maps that it seems impracticable to make a change.

The split-up strands seem to fall naturally into three groups, the upper group keeping close parallelism for the farthest distance north and apparently recording relatively slow movement in the beginning of the uplift. They probably record also some lowering of the lake by downward cutting at the outlet, but the amount was certainly small. In the Lake Superior basin the northern limits of the upper Algonquin beach have not yet been satisfactorily determined, and the amount and differential effects of the elevation there are not accurately known.

The middle group of Algonquin beaches comprises the Battlefield beach of Mackinac Island and two or three fainter strands not far below it. These, like those above them, converge to the hinge line.

The third group comprises the Fort Brady beaches, generally several in number and of moderate strength. These beaches lie close above the Nipissing beach and appear to converge with the other beaches to the hinge line.

The Kirkfield outlet was closed rather late in the life of Lake Algonquin. The idea held formerly that the postglacial uplifts of the land in the Great Lakes region were gradual and that they were evenly distributed through time is an error. The uplifting movements were evidently spasmodic, relatively sudden, and rapid. Almost all the deformation has occurred since the later part of the life of Lake Algonquin.

Port Huron-Chicago stage.—When the Kirkfield outlet was abandoned it seems probable that the overflow went first in greater part to Chicago, leaving only a relatively small part to flow south at Port Huron. But the Chicago outlet rested on a rock sill and held firm, and the Port Huron outlet deepened with relative rapidity, so that before long the lake level had fallen 10 feet and the Port Huron outlet had taken almost all the overflow away from Chicago. The Toleston Beach was formed at the time of this large-volume discharge at Chicago; any earlier beach of Lake Chicago controlled by the same sill must have been overwhelmed and worked over entirely by the Algonquin. On this hypothesis Toleston is in reality only a local name for the part of the Algonquin beach developed in the southern part of the Lake Michigan basin.

From the fact that the Kirkfield outlet appears to have carried the whole discharge of the upper three lake basins and that it was uplifted and abandoned rather late in the life of Lake Algonquin, the conclusion follows that while this outlet was active, the Chicago and Port Huron outlets were both left dry. This means that during this time the shores of Lake Algonquin throughout all the region south of the isobase of Kirkfield stood at a level at least a little below these two abandoned outlets. Hence, the upper Algonquin beach south of the isobase of Kirkfield was not made during the principal activity of that outlet, but during the Algonquin transition stage of the lake, when a considerable part of the overflow had left Kirkfield and gone to Chicago and Port Huron. The upper Algonquin beach was therefore a transition beach, made principally during the gradual lowering of the lake for 10 feet or more while the overflow was at Chicago and at Port Huron, with Port Huron gradually cutting down and gaining in volume. The character of the Algonquin beach agrees remarkably well with this conception of Lake Algonquin's history.

It was during the third or Port Huron-Chicago stage of Lake Algonquin that the larger part of the remarkable uplift of the Great Lakes region occurred. It began when the Kirkfield outlet was active, but soon raised Kirkfield higher than Port Huron and Chicago and shifted the outflow to these two places. The great uplift caused a remarkable northward splitting and divergence of the beaches blow the highest Algonquin. As a consequence the beaches of this stage are many in number and show a large vertical divergence northward. They seem to fall readily into three groups, the upper or main Algonquin, the Battlefield, and the Fort Brady. The main uplift began during the second or Kirkfield stage, but much the greater part occurred during the third or Port Huron-

Chicago stage, and the most rapid upward movement was during the making of the Battlefield group of beaches. At Sault Ste. Marie the vertical interval between the highest Algonquin and the Nipissing beaches is 365 feet, whereas in the area of horizontality (at Port Huron and Chicago) the interval between these same beaches is 10 or 12 feet.

Transitional stage.—At its very end Lake Algonquin appears to have been held up by a relatively small glacial barrier at some point in the Ottawa Valley east of Mattawa. When this last dam broke out or shrank back northward the waters rushed eastward from Lake Algonquin through the Mattawa Valley to temporary glacial lakes in the Ottawa, Petawawa, and Madawaska valleys, and thence to the Champlain Sea, and came to a settled level in the upper lake basins only when the eastward-flowing outlet had been established on the col at North Bay.

The relation in time of Lakes Algonquin and Iroquois is a matter of great importance in connection with the study of the deformation of the land. Certain facts seem to show that Lake Iroquois had already been established when the Kirkfield outlet was opened. The scoured bed of the outlet river of Lake Algonquin, called by Spencer Algonquin River, is strongly marked between the small lakes of the Trent Valley. At Peterboro an expanded part of it, which stood so near the level of Lake Iroquois that it may have been a land-locked bay of that lake, is filled with a great deposit of gravel and sand. This appears to be a delta deposit of Algonquin River and seems to show conclusively that this river emptied into Lake Iroquois. But the facts now available seem to show that Lake Algonquin existed also for some time after Lake Iroquois had fallen, for the scoured bed of Algonquin River appears to extend down to the Bay of Quinte at Trenton, and in all probability reaches below the present level of Lake Ontario. It even passes below the probable level of the marine waters that entered the Lake Ontario basin. But below Peterboro it seemed to the writer to show less scour than above and in some places seems to suggest a smaller stream. At present the relation of this lower part to the lake history is quite problematic, for no other fact indicating so low a level for the waters of the Lake Ontario basin at that stage is known. It may be that while Algonquin River was still flowing the ice front withdrew far enough to allow Lake Iroquois to be drained off for a brief time, and then readvanced, restoring the lake for another relatively long period.

POSTGLACIAL HISTORY OF THE GREAT LAKES REGION.

POSTGLACIAL LAKES.

NIPISSING GREAT LAKES.

With the establishment of the outlet of the upper throe lakes at North Bay a new order of things began. The ice sheet had disappeared from the Great Lakes region and no longer served as a dam or retaining barrier for any of its waters. This event may be taken as the place of division between the Pleistocene and Recent epochs of geologic time; the lakes (with their deposits) before this time belonging to the Pleistocene, those after it to the Recent.

At the beginning of this stage the Port Huron outlet had been abandoned. The new lake level; with its outlet at North Bay, lay in a plane which passed a little, though perhaps only a little, below the outlets at Port Huron and Chicago. During the later differential uplifting of the land, which occurred while the North Bay outlet alone was active, the isobase passing through that outlet became a nodal line on which the water plane swung. As elevation progressed the strands to the north of this line were abandoned and left dry, and those to the south were progressively submerged by the backing up of the water.

This order of changes continued until the North Bay outlet was raised as high as that at Port Huron. Then both outlets became active with the discharge divided between them. The beach made at this two-outlet stage has been called the Nipissing beach. In a strict sense, however, it is not the original Nipissing beach, made when the North Bay outlet alone was active, but a transitional beach made during the two-outlet stage. It might be called the Nipissing transition or two-outlet beach. The original Nipissing beach may be seen now only in the small part of the Lake Superior basin that lies north of the North Bay isobase or nodal line. This area, however, is so small and so close to the nodal line that the measurements thus far made have not yet disclosed any difference in the attitude of the old water plane on the two sides of the line. Theoretically there should be some difference and there probably is. South of the line the visible beach is the Nipissing transition or two-outlet beach, the original beach being everywhere submerged. But as no measureable change of plane has been found in crossing the nodal line the name Nipissing beach has generally been applied to the whole extent of the two-outlet strand.

The Nipissing beach thus defined has been traced with substantial continuity around all three of the upper lake basins and is, especially in the northern part of the area, much the strongest abandoned beach of the Great Lakes region. Its plane extends with almost perfect uniformity and with no certainly discoverable warping over all the northern parts of the basins. Except in the basin of Lake Superior, the uplift which afterward tilted this beach appears to have hinged about on the same line as the earlier uplifts which raised the Algonquin beaches; in the Lake Superior basin it lies some distance north of the Algonquin hinge line. South of this hinge line the Nipissing beach is horizontal at about 15 feet above present lake level. North of it the beach rises at the rate of about 7 inches to the mile in a direction about N. 22° E. The Nipissing beach is now about 117 feet above Lake Huron at North Bay, about 70 feet above at Sault Ste. Marie, 48 or 50 feet above at Mackinac Island, and about 130 feet above (110 feet

above Lake Superior) at Peninsula Harbor, near the northeast angle of Lake Superior.

The Nipissing beach shows remarkably strong development and maturity in all the northern parts of the basins, especially near the nodal line. For 150 miles or more south of the nodal line it is very strong, but farther south it seems gradually to diminish in strength, until in the area of horizontality it is little if any stronger than the Algonquin beach.

At the western end of Lake Superior the Nipissing beach appears to pass a little under the present lake level, a relation which probably accounts for the drowned condition of the shores and stream mouths of that region.

During the Kirkfield stage of Lake Algonquin the Port Huron outlet and St. Clair and Detroit rivers were abandoned and left dry, and they were abandoned in the same way during the time of the Nipissing Great Lakes. At both times Niagara River was robbed of the overflow of the upper three lakes, which amounted to 85 per cent of its volume.[1]

The Nipissing Great Lakes came to an end when the northern uplift raised North Bay enough to close that outlet and shift the whole discharge back to Port Huron. With this change the modern Great Lakes have their beginning.

POST-NIPISSING GREAT LAKES.

After the overflow came back to Port Huron the northern uplifting continued, though apparently more slowly, there being a series of fainter beaches on the slope below the Nipissing beach. One beach, especially, is slightly stronger than the rest and seems to mark a pause in the uplifting movement. This beach is called the Algoma beach because of its development at Algoma Mills, Ontario, where it lies about 50 feet above Lake Huron and 35 feet below the Nipissing beach. The Algoma beach has been found at many places farther south in a position a little more than halfway up from the present shore to the Nipissing beach.

On the north shore of Lake Superior a beach of moderate strength, standing in about the same relation below the Nipissing, was at first thought to be a beach belonging to the Lake Superior basin alone and determined by the outlet of that lake at Sault Ste. Marie. It was called the Sault beach[2] and was thought to swing on the isobase of that place as on a nodal line. It is believed to be submerged on the south shore of Lake Superior and around the west end. The Algoma beach appears to be due to a pause in the uplifting movement. In all probability there is a beach corresponding to the original description of the Sault beach, but it has not been certainly identified.

LAKE ERIE.

After Lake Erie became separated from Lake Ontario it ceased to be a glacial lake and from that time on was entirely independent of the ice sheet. By the time the separation had been accomplished following the fail of Lake Lundy, the basin of Lake Erie had probably been brought nearly to its present attitude. Since its separation it has had two low stages, while the Kirkfield and North Bay outlets were active, during which it was not receiving the discharge of the upper lakes. The Fort Erie beach, declining gently westward along its north shore from Fort Erie, Ontario, where it is 15 feet above the lake, is, at least at its east end, the correlative of the beaches of Early Lake Algonquin and of the Port Huron-Chicago stage of the greater Lake Algonquin. The two low-stage beaches made in the basin of Lake Erie during the Kirkfield stage of Lake Algonquin and during the Nipissing Great Lakes lay very nearly in the same piano, and both are now everywhere submerged.

[1]Taylor, F. B., Niagara folio (No. 190), Geol. Atlas U. S., U. S. Geol. Survey, 1913, pp. 21-22.

[2]Taylor, F. B., The second Lake Algonquin: Am. Geologist, vol. 25, March, 1905, pp. 166-167.

PRESENT STABILITY OF THE LAND.

In the northern part of the upper lakes many evidences, such as the newness of the modern shore line and of the mouths or lower courses of the Nipigon and other northern rivers, strongly suggest very recent or progressive emergence. In other parts of the lake region the evidence seems to be against progressive change. Gilbert found what he believed to be evidence of progressive change in the records of the lake gages, and he estimated the rate of differential uplifting. Recent investigations, however, have made changes in the data which he used and have necessitated a modification of his results.

Since the discharge returned to Port Huron, St. Clair River has cut down its bed by about 15 feet and Detroit River by half as much. This has greatly reduced the drowning of tributaries caused by the return of the full volume to Port Huron after the abandonment of that outlet during the time of the Nipissing Great Lakes.

In the western parts of the Lake Erie and Lake Ontario basins recent raising of the water level is indicated by drowned stream courses and in the Lake Erie basin by submerged stumps and creek beds described by Moseley as occurring in Sandusky Bay. These facts seemed at first to suggest that the tilting might still be in progress. But the drowning effects in these two basins, at least to depths of 10 or 15 feet, are probably due to the return of the large volume of discharge to Buffalo after the relatively long period of small discharge during the time of the Nipissing Great Lakes rather than to very recent or progressive tilting of the land. Both at Buffalo and on the St. Lawrence the outlet is on a rock sill and the downward cutting has been slight.

POSTGLACIAL MARINE WATERS IN THE OTTAWA AND ST. LAWRENCE VALLEYS AND IN THE LAKE ONTARIO BASIN.

When the ice sheet withdrew from the basin of Lake Ontario and the northern slope of the Adirondacks, the sea entered in its place and covered a large area. Its approximate limits are indicated by clays, gravels, and sands, which contain fossil remains of marine organisms such as are now living in the Gulf of St. Lawrence. The upper limit of the marine waters was about 350 feet at Plattsburg, N. Y., and 523 feet at Covey Hill, Ontario. It was at least 460 feet at Welsh's siding near Smiths Falls, Ontario, and may have been much more, for at the last-mentioned place the remains of a whale have been found in a gravel bed, definitely fixing a minimum upper limit of marine submergence. The height of marine submergence at Montreal is reported to be about 625 feet. On the south side of St. Lawrence River a well-defined beach marks what is taken to be the upper limit of the marine waters and has been called by Gilbert the Oswego beach. It declines gradually toward the southwest and passes under the present level of Lake Ontario about at Oswego.

The marine waters appear to have entered the basin of Lake Ontario some time in the later part of the time of Lake Algonquin. Uplift appears to have been in progress when the sea entered and to have soon ended the marine connection by raising the outlet above the sea. At the end of Lake Algonquin the sea probably did not extend above Cornwall and Ottawa.

CHAPTER XIII.
GLACIAL LAKE MAUMEE.

By FRANK B. TAYLOR.

EARLY INVESTIGATIONS.

Glacial Lake Maumee has been discussed by Mr. Leverett,[1] who described the Port Wayne outlet and the highest and middle beaches in considerable detail and briefly discussed the deformation of the beaches and the general relations of the lake to the ice sheet. Later[2] he described the shores of the lake in Wayne, Washtenaw, and Lenawee counties. Still later, in preparation for this monograph, Mr. Leverett and the writer made further studies in Lapeer, Macomb, and Oakland counties, especially with regard to the beaches and to the relations of the moraines of that region to the beaches and to the Imlay outlet. (See Pl. XIV.)

Since Mr. Leverett's earlier work was done the greater part of northern Ohio has been surveyed and mapped by the United States Geological Survey, making possible more accurate determinations of altitude on all the beaches and furnishing better foundation for studies of their deformation. Discrimination and correlation of the beaches of different parts of the area are also facilitated by these maps. Some helpful results have been obtained by putting the results of earlier work upon the new maps and studying them in the light of the later, more accurate altitudes. In this way it has been possible to correct some important errors due to aneroid barometer and to inaccurate railroad levels.

DISTRIBUTION OF MAUMEE BEACHES.

The highest and middle beaches of Lake Maumee are fully described by Mr. Leverett,[3] and it is not necessary to add to his general description. There is, however, a stretch in Ohio between Delphos and Findlay in which, since 1907, the writer has made some detailed studies of them with the aid of the topographic maps and has found some unusual features and some interesting data bearing on the attraction of the ice in deforming the surface plane of Lake Maumee.

The lowest beach of Lake Maumee is briefly mentioned by Mr. Leverett[2] but has not been described elsewhere. No systematic effort has been made to trace this beach except between Tecumseh and Rochester in Michigan, but it has been found at intervals northeastward as far as Romeo in Macomb County and south westward nearly to the Ohio-Michigan State line. It has also been found at a number of places in Ohio eastward from Delphos and appears to be recognizable at many places by its influence on the contours of the topographic maps. It appears to be particularly well developed from the Defiance moraine eastward into Pennsylvania and was formerly regarded as the middle beach of Lake Maumee, the one above it being regarded as the highest. Now, however, this correlation is thought to be wrong and the two Maumee beaches which extend eastward from the Defiance moraine are regarded as the middle and lowest beaches, and the highest beach is thought to have been either not formed at all in the interval or else to have been overlapped or destroyed by the lake at the time of the middle beach.

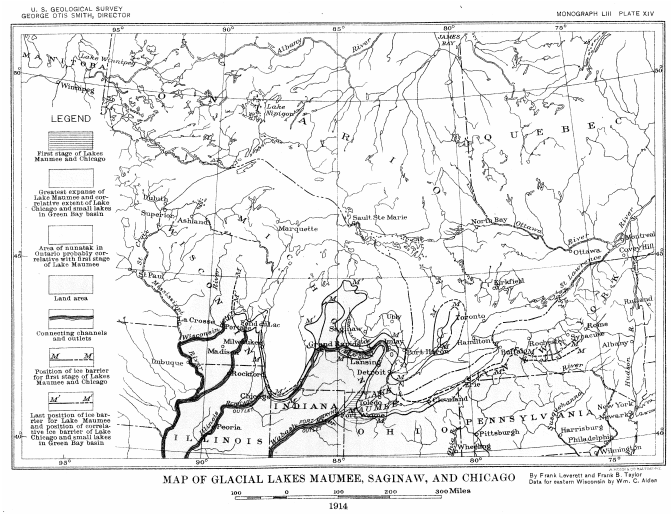
[1]Mon. U. S. Geol. Survey, vol. 41, 1902, pp. 710-740. In this passage Mr. Leverett reviews earlier writings relating to this lake, including papers by Bela Hubbard, G. K. Gilbert, J. S. Newberry, C. R. Dryer, A. A. Wright, and others, and he notes the fact that the name Lake Maumee was first applied by Dryer in 1888, in his report on the "Geology of Allen County, Ind."

[2]Ann Arbor folio (No. 155), Geol. Atlas U. S., U. S. Geol. Survey, 1908, p. 7; revised ed., 1915, p. 7.

[3]Mon. U. S. Geol. Survey, vol. 41, 1902, pp. 714-740.

It seems quite certain that the highest beach is not represented in this interval by a strong separate shore line, like that west of the Defiance moraine, or it could hardly have been overlooked. That it was not formed east of the Defiance moraine seems improbable, because east of this same moraine in Michigan it is strongly developed in independent form and all three beaches extend up to the vicinity of the Imlay outlet. If it was made inside the Defiance moraine in Michigan, it should have been formed inside the moraine in Ohio. It is therefore regarded as possible that the highest beach in this interval stood at about the same level as the middle, and that fragments of the highest may lie in

discordant relations behind the middle. More field studies bearing on this question are needed.



[Plate XIV. Map of glacial Lakes Maumee, Saginaw, and Chicago]

If the middle beach is, in fact, as high or higher than the first or highest beach on the south side of the basin east of the Defiance moraine but not west of it, the cause of such a relation is somewhat difficult to find. At present no satisfactory explanation seems available—nothing better than an arbitrary assumption of slight local subsidence of the land after the formation of the highest beach and before the formation of the middle one. If the highest beach were confined to the basin west of the Defiance moraine, both north and south of Maumee River, the relations would be simple enough, but such does not appear to be the case. Somewhat similar conditions occur in connection with the beaches of Lake Arkona but nowhere else, so far as is known.

CHARACTERISTICS OF LOWEST BEACH AND RELATED DELTAS.

Mr. Leverett points out[1] that the lowest beach has a "washed-down" appearance, as if it had been submerged and modified. Later investigations in connection with Lake Arkona (p. 362) have fully established the fact that beaches have been submerged and modified and in places have been almost totally destroyed. Certain characteristics qualities very clearly distinguish such modified beaches from others that have not been submerged, and these same characters are distinctly shown by the lowest beach of Lake Maumee. Even where composed of gravel, it is more fragmentary than other gravelly beaches, and at most though not at all points it has a lower relief than normal gravel beach ridges. In some intervals the beach deposit appears to be absent entirely, and in others it has a "washed-down" appearance and its ridges and gravelly deltas contain more clay and have a stiffer soil than normal beaches and deltas.

A characteristic feature of the Arkona shore lines is the remarkable way in which the deltas connected with them protrude beyond the general line of the shore. The Arkona delta of Huron River carries the beaches out into the lake 2 or 3 miles beyond the general lake border. In less degree the gravelly deltas associated with the lowest beach of Lake Maumee show the same habit of protrusion beyond the general line of the shore. This relation appears to be accounted for mainly by the fact that these deltas were built by streams entering the lake in beds that had not been previously trenched to or below the lake level of that stage. Neither at their mouths nor in their lower courses did these streams have any preexisting valley or bed in which the coarser sediments could lodge. Hence, all of their sediments were carried beyond the original contour of the shore and were deposited in a mass that carried that contour out into the lake. It was quite different with Lake Whittlesey, for that lake was superposed on a surface previously trenched by streams, and the trenches made by those streams absorbed nearly all the materials commonly built into deltas, so that Lake Whittlesey had no protruding deltas, but only estuarine or valley-set deltas.

Rouge River at Plymouth made a rather prominent delta in connection with the lowest beach, and the beach ridge associated with it is greatly strengthened. At Rochester the delta is not quite so prominent but has the common characteristics. At Ypsilanti the delta is very prominent and extends about 2 miles beyond the general shore line. East of Ypsilanti it contains one or two strongly marked distributary channels. The deltas south of Saline and Tecumseh are not so prominent, but they show the same modification by submergence.

These characteristics of the lowest beach and of the deltas associated with it seem to leave no doubt that this beach, although located farther down the slope, was made before the middle beach, and that after it was made the lake was raised to the level of the middle beach. While the latter beach was being made, the lowest beach was submerged and was undergoing modification.

[1]Ann Arbor folio (No. 155), Geol. Atlas U. S., U. S. Geol. Survey, 1908, p. 7.

TOPOGRAPHY OF THE BEACHES.

ALTITUDE.

The altitudes of the highest and middle Maumee beaches were originally determined by Mr. Leverett[1] mainly by aneroid barometer checked by railroad levels. The Survey's topographic maps covering the course of the beaches between Tecumseh and Washington in Michigan, including those of the Ann Arbor quadrangle, do not show any notable error in previous measurements. The maps of areas from Findlay to the western edge of the Delphos quadrangle indicate that the altitude of the highest and middle Maumee beaches and of the vicinity of the head of the outlet at Fort Wayne, Ind., is 5 or 6 feet higher than was previously

indicated. In the following résumé of variations in altitude[2] the details are given somewhat fully, because some of them will be referred to later.

By the older measurements the altitude of the highest Maumee beach is 775 to 780 feet at the head of the outlet in the vicinity of Fort Wayne and New Haven, Ind. Near the Ohio-Michigan State line, 50 to 75 miles to the northeast, it is 20 to 25 feet higher. At West Unity and Fayette, Ohio, the beach stands close to the railroad stations, at an altitude of 801 and 798 feet, respectively. At Fairfield, Mich., the altitude of the geodetic station is 799 feet.

Mr. Leverett gives the altitude of the highest beach as 795 to 805 feet throughout the Ann Arbor quadrangle. The strong beach is generally above 800 feet and at a few points rises to 810 or 812 feet. Two points that reach above the 820-foot contour are thought to involve some error in contouring, for they seem too high for any phase of normal development even for a storm beach. If the measurements are correct, such forms are likely to have had some special mode of formation, such as the shoving of ice on shore by the wind or, more probably, some occurrence associated with the formation of the deltas of Huron River in Lake Maumee.

The highest beach continues at about the same altitude (800 to 810 feet) to a point 4 or 5 miles north of Birmingham, where it begins to rise. It is 805 feet 2 miles west of Birmingham, but at the north edge of the Rochester quadrangle, 11/2 miles north of Washington, it is 820 feet. From Clinton River northward about 25 miles to Imlay the beach rises nearly 40 feet or to an altitude of 850 feet above sea level. The beach was traced by the writer to a fading termination, at an altitude of a little more than 855 feet, in northwest sec. 21, Goodland Township, Lapeer County, nearly 6 miles north of Imlay.

On the south side of Lake Maumee the early measurements made the altitude of the highest beach 775 to 785 feet from Fort Wayne to Cleveland. The new topographic maps show it to be 785 to 790 feet from Delphos to Findlay. Eastward from the Defiance moraine (see p. 279) the middle beach of Lake Maumee marks the limits of the lake, so far as yet recognized.

By early measurements the middle beach was found to have an altitude of 760 to 765 feet, or 20 to 25 feet below the highest beach from the head of the outlet east of Fort Wayne to Bryan, Wauseon, and Pettisville, Ohio. At Fairfield, Mich., it had an altitude of about 775 feet, and in the Ann Arbor quadrangle of 780 to 785 feet, almost everywhere 20 to 25 feet below the highest beach. It rises from 785 feet at Clinton River to 825 feet at Imlay. Toward Imlay it is 25 to 30 feet below the highest beach. East of Almont it is 821 feet above sea level and 19 feet below the highest beach. Its bars on the moraines at Smith station and Berville are 820 feet above sea level.

The middle beach is stated by Mr. Leverett[3] to have an altitude of about 765 feet between Fort Wayne and Cleveland. But the middle beach is not well developed in the vicinity of the outlet, and its identity and continuity among several weak ridges on the flat plain extending eastward from New Haven, Ind., into Ohio have not been fully worked out. Some of the lower of these ridges probably belong to the lowest beach, the place and relations of which in this district remain to be determined.

[1]Mon. U. S. Geol. Survey, vol. 41, 1902, pp. 723-739.

[2]Mainly from Mori. 41, the Ann Arbor folio (No. 155), and the new Survey sheets in Ohio.

[3]Mon. U. S. Geol. Survey, vol. 41, 1902, p. 739.

The middle beach enters the Delphos quadrangle at an altitude of 770 to 777 feet and holds it as far as Pandora. From Pandora to Benton Ridge it rises to over 790 feet and is associated with some exceptional features. (See p. 340.) It is in many places not more than 10 feet and in most places not more than 15 feet below the highest beach. In a few places the interval is greater than 15 feet. These variations of vertical interval are due chiefly to variations in development; where the highest beach is weak and the middle one strong the interval is less than the mean, and where the highest beach is strong and the middle one weak the interval is greater than the mean.

Eastward from the Defiance moraine the middle beach appears to mark the limits of Lake Maumee. It rises from about 770 feet near Leipsic to 780 or 782 feet near Berea and in Cleveland. From Cleveland northeastward to Mentor, a distance of a little over 20 miles, it rises to 791 feet. Eastward from Mentor it runs at nearly the same level about to Ashtabula, where all the beaches begin to rise. At the Ohio-Pennsylvania State line the beaches are all 8 or 10 feet higher than at Ashtabula, and from the State line they all rise more rapidly northeastward.

The lowest beach is weak and fragmentary but is fairly well defined in the Delphos, Columbus Grove, Bluffton, Ottawa, and Deshler quadrangles in Ohio. Its altitude is a little above 750 feet. Several points show 752 feet and others as much as 757 or 758 feet. In Michigan this beach is generally at or slightly above 760 feet, but in Ohio it averages about 755 feet. The lowest beaches near the Fort Wayne outlet are near enough to this level to suggest their probable identity.

So far as observed in Michigan the lowest beach is everywhere about 20 feet below the middle one. It has not been observed north of Romeo, in Macomb County, where it is a weak feature at about 790 feet, the middle beach being at 810 feet.

Since the discovery of the lowest beach some uncertainty has arisen as to the identity and northeastward extent of the middle and lowest Maumee beaches, but there has been no opportunity to reexamine the ground. It seems likely, as stated above, that the delta-like deposits at Fairview, Pa., and the faint beach and delta deposit at Girard, Pa., belong to the lowest beach. Their height above the Whittlesey beach

indicates this, and if such is their relation it may be that somewhere west of Girard the middle beach becomes too weak to be traced. However, if the lowest beach was made at a back-step halt of the ice front and the middle beach after readvance and a raising of the lake level, as supposed, then some part of the lowest beach was overridden and obliterated by that readvance. The middle beach would then be faint at its end and could not, in all probability, be traced so far to the northeast. The deposit at Girard, Pa., has an altitude of 770 to 775 feet and is 25 or 30 feet above the Whittlesey beach.

A careful comparison of altitudes seems to show all the beaches in the Oberlin quadrangle to be a little low, possibly because they are protected against the dominant western winds by the high ground in the Vermilion quadrangle to the west. The fact, however, that all beaches are affected alike, although all are not equally protected, renders this explanation somewhat unsatisfactory.

ICE RAMPARTS.

RAMPARTS ON MODERN LAKES.

In Indiana, Michigan, Iowa, Wisconsin, Minnesota, and probably elsewhere there occur what are known as "walled" lakes[1]—lakes bordered on one or two sides by a narrow ridge or wall of bowlders a few yards back of the shore. Such ridges, called "ice ramparts," are commonly 2 to 5 feet high and on some lakes run for long distances. Modern ramparts invariably rest on flat ground and face lakeward over a flat shore and a shallow, smooth lake bottom from a few rods to several hundred feet wide.

[1]One of the "best accounts of these lakes and of the formation of rampart ridges is by E. R. Buckley (Ice ramparts: Trans. Wisconsin Acad. Sci., vol. 13, 1901, pp. 141-162). Dr. C. A. White also discussed walled lakes in his official report as State geologist of Iowa, published in 1870.

Ice ramparts are the product of wind and floating ice, the ordinary ice coating of the winter season. Toward spring the ice covering the lake thaws around the edge, becomes loosened from the shore, and then by heavy gales, usually from a westerly direction, is driven with great force upon the easterly or southeasterly shores. On ordinary shores with bluff banks and steep descent the ice simply batters the shore and breaks up, producing no unusual result. But if the offshore slope be very gentle and the ground back from the water's edge low and flat, the ice meets relatively slight resistance and by sliding on the bottom rides up out of the water onto the land, sometimes pushing scores of feet beyond the water's edge.

In sliding up the gentle incline the ice is cracked at intervals, but the pieces are usually not disjointed nor separated and the whole mass is pushed forward with tremendous force, carrying everything movable before it and gathering up a ridge of mixed materials to be finally left in the form of a rampart.

RAMPARTS ON LAKE MAUMEE.

INTERPRETATION.

So far as the writer is aware, the occurrence of this process on a large scale in the past has not been clearly inferred from anything observed hitherto, but in the district under consideration a remarkable group of ridges associated chiefly with the highest beach of Lake Maumee shows peculiarities of form, composition, and general relations that are inexplicable, except on the supposition that they are ice ramparts. On this supposition all of their peculiarities are clearly explained. These ridges occur on the south shore of Lake Maumee, chiefly between Delphos and Findlay (see Pl. XV), where the trend of the old shore is southwest and northeast. Their principal development is between Gomer, 8 miles east of Delphos, and Benton Ridge, 22 miles northeast of Gomer.

The ice ramparts of Lake Maumee are in many respects very different from the forms common on the shores of the small lakes. In the first place the whole phenomenon is on a scale many times greater than that of the small lakes. Instead of being composed mainly of bowlders, pebbles, and rubbish, those of Lake Maumee are composed chiefly of gravel and clay, the clay in many places making more than half the mass.

The early students of this region appear to have paid no special attention to these ridges but to have regarded them as ordinary beach ridges. Although their situation and relations to the shore of Lake Maumee and to the beach ridges mark them as closely related forms, their clayey composition excludes them from the category of true wave-made deposits. They show also peculiarities of plan and general relations that are abnormal for beach ridges formed under the very simple conditions of this district, where the country for several miles north of the beaches is extremely flat and even, its general slope being north-northwest 5 to 10 feet to the mile. The extreme shallowness of the lake waters for several miles offshore was probably not equaled elsewhere in the lake region. More particularly was this true when the lake was first formed and the waves had not yet had time to modify the lake floor.

Normal beach formation on such a shore generally results in the formation of beach ridges on straight or very gently curving lines following the course of a contour. It does not tend to the formation of crooks nor sharp bends, nor, with only small streams and low gradients, to the formation of notable delta irregularities. As the present stream beds of the region are narrow and only slightly depressed in the flat plain and were less depressed in glacial times than now, there appears to have been no cause in the topographic environment for exceptional or peculiar beach forms.

DISTRIBUTION AND CHARACTER.

Within 3 miles of Columbus Grove, four branch ridges, 3 or 4 miles long, appear to split off from the south side of the middle beach of Lake Maumee and run southwest a

little more south than the main ridge. These branch or spur ridges are more like true beach ridges than the fragments east of Pandora, because they have suffered less modification. They appear to be connected with the middle beach but are mostly higher, especially toward their southwest ends, where they rise to the level of the highest beach.

These spurs have four marked peculiarities: (1) Their southwest ends all bend sharply south, leaving the direct lines of continuation unoccupied; (2) most of them show angular crooks and turns that are plainly not normal to the conditions of beach formation in this district; (3) they divert the course of the streams toward the northeast, which is contrary to the direction that would be expected if they are true beach bars built by waves; (4) though their composition varies considerably they contain much clay, in many places more than 50 per cent.

The southwest direction in which the spur ridges split off is such that they could have been built as spits or bars only by shore drift coming from the northeast. If so built they must have been made before the building of the Defiance moraine, for since that moraine was built the dominant wave action and shore currents were from the west and southwest, and the wave action and shore currents from the northeast were relatively weak because of the narrow expanse of water in that direction. Their relations, however, are such that they could not have been built from that direction.

One of the most striking peculiarities of the spur ridges is the bent end which characterizes each. Six or seven such ends occur between Gomer and Columbus Grove and several other less prominent ones farther east. Their relations to the streams and their horizontal plan are shown on Plate XV.

One of the spur ridges which terminates a mile east of Vaughnsville is about 21/2 miles long. Most of it is straight and simple in form, its chief peculiarity being its bent end and the relation of this to Sugar Creek. In shape it resembles a hockey stick, the sharply bent end at the southwest corresponding to the bent end of the stick. It looks as though the ridge had originally extended in a straight line southwest to the creek and had there been united directly with the ridge on the west side, the end of which, now one-third mile away, is not bent. The ridge does not come up to the bank of the creek on the east side nor does the opening contain deposits representing the ridge. If any were ever there they must have been removed. The bent end is of the proper length to supply the missing part, and the effect is as though the end east of the creek had been pressed or pushed back a quarter of a mile or more by some agency acting from the west or northwest.

The bent end looks like an inward curving spit or hook on the map, but it is in reality not of that nature. The environment is not that which favors the making of hooked spits but is typical of that which leads to the making of straight-line or very gently curved beach forms. The ground on which the ridge rests is extremely flat. The stream even now is only slightly depressed where it passes through the ridge, and at the time Lake Maumee existed the depression was certainly much less. No wide, shallow troughs are associated with these streams, as is plainly shown by the contours of the topographic maps and by the remarkably even, nearly straight course of the middle Maumee beach ridge westward from Columbus Grove. This beach shows that at the time of its formation there was no inequality of the land surface of sufficient magnitude to counteract the normal tendency to the formation of rectilinear shore lines. Conditions were similar during the formation of the highest beach and of the spurs with bent ends.

There appears to have been no reason for the formation of hooked spits at the places where the bent ends are found. There was no depression or valley toward the south up which they could turn. Indeed, these bent ends usually run up onto ground somewhat higher than that where the spurs split from the main ridge. Two miles south of Columbus Grove and in one or two other places the bent end is wider and higher than the rest of the spur, as though the material of a section of the spur had been pushed obliquely into a smaller space.

Most of the spur ridges show peculiar crooks or sharp bends that resemble the angles of the bent ends, but in which there is no break. Good examples are shown south and southeast of Vaughnsville and south and east of Columbus Grove. This peculiarity is just as abnormal as the bent ends for true beach formations under the simple conditions of this district.

In another way these forms are decidedly abnormal. In the making of beach ridges on shores conditioned like this, the gravel and sand for the building of the ridges is not derived from the cutting of sea cliffs nor in any important degree from sediments brought in by small streams like those of this district but is gathered mainly from the bottom of the lake in the shallow water offshore. Where the water is shallow for a long distance out, storm waves break at a considerable distance off shore and do a great work of erosion upon the bottom. They pound it and stir it up, ultimately carrying away the finer sediments to deeper water and sweeping the coarser sediments up the slope into a beach ridge. Thus, in front of a beach ridge of fairly mature development, there is commonly a belt of considerable width—a “surf-wasted zone”—which has been cut away by the subaqueous work of waves and currents. None of the spur ridges of this district has a surf-wasted zone. In strong contrast, the middle beach of Lake Maumee, a mile or so away, has a well-developed zone of this kind.

When to the several peculiarities adduced is added the clayey composition of the ridges, it becomes impossible to explain them as normal, unmodified products of wave and shore current action. But, as will be pointed out below, all of their peculiarities are clearly explained if the ridges are regarded as ice ramparts.

East of Pandora the rampart ridges have somewhat different expression. They are more nearly straight but

vary more in strength and height and are more largely composed of clay. Some of their higher parts reach an altitude of 800 feet. The highest beach of Lake Maumee has an altitude of 785 to 790 feet, and the ridges east of Pandora seem quite clearly to belong to the time of that beach, as do also some smaller, scattered fragments 3 miles south of Pandora and 3 to 4 miles southeast and south of Columbus Grove.

From Pandora to Benton Ridge the middle Maumee beach seems to rise 15 feet and runs obliquely across the trend of the rampart ridges. It has the appearance of having been superposed upon the rampart ridges, and there is reason to believe that the ramparts formerly extended farther to the northeast on ground which is now below the level of the middle beach.

FORMATION.

In its early stages Lake Maumee was in all probability covered with ice of considerable thickness during winter seasons. In the spring the margin of the ice, where it had been attached to the shore, was the first to thaw, leaving a lane of open water between it and the land. The ice had thus become loosened from the land and floated freely on the water. While in this condition, strong winds from the west or northwest drove it toward the east or southeast, and the force of the wind and the momentum thus attained carried it up the gentle slope.

In this district the shore and lake bottom conditions at the time of the highest beach of Lake Maumee were extremely favorable for the formation of ice ramparts. When the vast ice cake or floe impelled by the wind began to move toward the shore its lower edge first encountered the gently sloping clayey bottom of the offshore shallows. This offered relatively little resistance. A considerable body of the mud with whatever was resting on it was pushed forward at the edge of the ice. At length the upward inclination of the bottom raised the marginal part of the ice slightly out of its horizontal position and made it conform to the plane of the slope. Probably the ice was cracked at intervals in this process, but it was not broken up and displaced. When the edge of the ice reached the beach line, the materials which the waves had gathered were incorporated with the mud and pushed along up the slope. When the shoreward movement of the ice stopped, this body of clay, gravel, and sand was left as the rampart ridge. The bent ends were pushed back at the edge of ice moving from a northwesterly direction, and the crooks and thickened ends were produced and the clay contributed in the same way. Such a process requires no notable depression in the gap west of the bent ends nor any surf-wasted zone in front of the spurs.

In all probability the ice cakes involved were generally several miles in extent along the shore. This is indicated by the length of the rampart spurs. That the ice cakes were not much broken along their shoreward edges is also indicated by the straightness of most of the longer spurs. Still the occasional sharp bends and the bent ends may be in part due to cracking of the ice on lines normal to the shore and to unequal shoving of the different parts. Whether the ramparts are in each case the product of a single onshore movement or are the cumulative product of a few or of many such movements can not now be stated. The latter alternative would seem the more likely one, but very little evidence supporting it was observed.

The larger scale of the forms in this district as compared with modern features of similar origin points to some interesting conclusions relating to the conditions which existed at that time. It was stated above that most of the rampart ridges seem to be related to the time of the highest Maumee beach. It is worthy of note that the conditions were more favorable for onshore movement of the ice then than at later times, for, when the continental ice sheet first withdrew from this ground and Lake Maumee first occupied it, the slopes from the lake bottom 4 or 5 miles offshore to the land surface a few miles back of the shore were more even and uniform than they have been at any later time, because they had not then been modified either by surf-wasting offshore or by the building of beach ridges on shore. Hence, the first ice cakes that were blown on shore met less resistance and probably pushed farther up the slope than any of the later ones. As the surf-wasted bench became more pronounced in its development and the beach ridges larger and more bulky, the conditions favoring the shoving of ice floes above the shore line grew less marked. For this reason the highest of the ramparts and those farthest back were made first and the series down the slope to the northwest were made successively later. The older ridges generally contain more clay than the later ones. Some of the fragments and bent ends indicate displacements amounting to a mile or more, and in some places the displacement may have been even greater.

As the shore of Lake Maumee westward into Indiana is of the same character and the beaches westward from Delphos show very little modification of the kind here described, it seems certain that the westerly and northwesterly winds were the chief forces that produced the on-shore shoving of the ice. That part of the shore that faces the northwest or north-north west-shows the strongest development of ramparts. The shoving seems to have been done mainly from the west-northwest or in a direction slightly oblique to the slope. This, of course, had the effect of reducing the relative degree of inclination of the slope up which the ice moved and facilitated the process. In general the bent ends and sinuosities seem best accounted for by shoving from the west-northwest.

If the beachlike clayey ridges of this district are in fact ice ramparts and were produced in the way here suggested, their magnitude and the scale of the movements involved in their displacement seem to require thicker ice in the ice cakes or floes on Lake Maumee than occurs on any modern lakes. Ice at least 5 to 10 feet thick seems indispensable to the validity of the explanation here offered. But a greater thickness of the winter's ice

on Lake Maumee might be expected in the glacial period when the front of the continental ice sheet was probably not more than 40 or 50 miles away. It is not impossible that a more detailed study of these forms would lead to more definite conclusions as to the thickness of the ice at that time.

After the surf-worn bench offshore became strongly developed, on-shore shoving of the ice ceased to be so important, but apparently it did not cease to play a part in determining the composition of the beach ridge in some localities. The middle beach ridge a mile or two east of Delphos is composed largely of clay, and the upper ridge in Van Wert was found by Mr. Leverett[1] to contain clay. In all probability these characters are due to the same process of on-shore shoving of floating ice by the wind—an action which, though strong enough to push much clay up onto the beach, was too feeble to break or displace the ridge as it had done formerly. The lowering of the lake level from the highest to the middle Maumee beach reduced the offshore depth and tended to favor a renewal of rampart making. But the slope back from the water's edge was less favorable, being steeper than formerly, and probably caused the ice cakes to break up against the beach ridge.

[1]Mon. U. S. Geol. Survey, vol. 41, 1902, p. 728.

OTHER GLACIAL RAMPARTS.

Somewhat similar effects on a smaller scale may have been produced in other localities in the Great Lakes area. Some may be associated with the Whittlesey, Arkona, and Warren beaches in the flat regions in Ohio north and northeast of the district here described. In the Quanicassee region at the southeast side of Saginaw Bay some of the heavy ridges may be largely due to ice shoving, for in January, 1910, a gale from the west-southwest piled the ice of Saginaw Bay on shore near Sebawaing into a ridge 10 miles long and in some places 70 feet high. The floor of the shallows there is flat limestone.

DEFORMATION OF WATER PLANE BY ICE ATTRACTION.

THEORETICAL CONSIDERATIONS.

It has been calculated theoretically by Woodward[1] that an ice sheet of a certain thickness, configuration, and extent would draw up the water surface of a lake standing in contact with it by a certain definable amount. Woodward's statements are often quoted, but a careful examination of his paper makes it clear that the conclusions usually drawn from them are unwarranted.

Woodward adopts certain definite assumptions as the basis of his calculations. He assumes an ice cap at its center 10,000 feet thick, covering the polar regions and extending symmetrically to the thirty-eighth parallel. Then he gives a series of values for the deformation of the water plane based on different assumptions as to the slope of the surface of the ice cap from its center to its edge. One of these assumptions is that the ice cap is of uniform thickness throughout (has no slope from center to edge); that is to say, that it is 10,000 feet thick at its edge on the thirty-eighth parallel and that its front is a vertical cliff of ice 10,000 feet high. For this particular assumption Woodward finds that the water will be raised 573 feet at the edge of the ice cliff and will slope away at an average rate of 1 foot to the mile for a distance of 1° from the ice edge. This assumption, though very far from the conditions of the concrete case under discussion, is invariably the one quoted, and this despite the fact that Woodward gives results for several other assumptions which come much nearer actual conditions. No attempt is made here to apply Woodward's analysis to the concrete cases found, but it seems worth while to present certain facts bearing on the problem.

AREA OF HORIZONTALITY.

Several places within the Great Lakes region might be expected to afford a test of this theory, and it is important to examine the data in these localities and to place the facts on record for the use of any who may wish to pursue the inquiry further. If the old shore lines show the supposed deformation by ice attraction, it is desirable to determine its amount and to recognize it so that it can be eliminated from the estimates of the amount of deformation due to other causes, where greater deformation occurs, and also in order that regions unaffected by other causes of deformation may be recognized clearly and the slight deformations due solely to ice attraction distinguished. The localities where the theory might be tested are not all in the area under discussion, but they may be considered briefly.

In discussing the deformation of the Great Lakes region it has for some years been regarded as a fact that all the beaches south of a certain ill-defined line or narrow zone are horizontal. The line runs from Ashtabula, Ohio, through the central part of Lake St. Clair, passes 4 or 5 miles north of Birmingham, Mich., and crosses Lake Michigan westward from a point a few miles north of Grand Haven. South of this line the old water planes depart so little from horizontally that the departures were regarded as possible errors of measurement, or as lying within the limits of the natural range of altitude of normally developed shore formations, or as due in part to ice attraction. This was more particularly the attitude of mind of students of the subject before the publication of the more accurate topographic contour maps made in recent years by the United States Geological Survey. In certain districts now covered by these maps more refined studies can be made, but the maps now cover only a few limited areas.

The line referred to above was taken to be the isobase of zero, or line of no deformation. Apparently the land to the north of it has been uplifted and deformed, and the land to the south of it has remained unaffected and in its original attitude of horizontality. In this sense the isobase of zero has been called a "hinge line" and the region south of it is the so-called "area of horizontality."

[1]Woodward, R. S., On the form and position of the sea level: Bull. U. S. Geol. Survey No. 48, 1888, pp. 13-86.

DEFORMATION AT OR NEAR THE EDGE OF THE ICE.

DEFORMATION BETWEEN COLUMBUS GROVE AND FINDLAY.

Field work.—Considered with reference to accuracy and reliability of data the district between Columbus Grove and Findlay, Ohio, affords the best field for the study of ice attraction now available. (See fig. 4.) In this district the area occupied by the highest and middle Maumee beaches is covered by some of the newly made topographic maps with contour intervals of 10 feet. Ice shoving, which occurred chiefly in connection with the highest beach (see p. 338), modified it so extensively that its tracing eastward from Columbus Grove is very uncertain; however, it does not appear to rise in that direction. It seems certain that the highest beach in this vicinity was made before the Defiance moraine and extended a considerable distance farther east, being overridden by the readvance to this moraine.

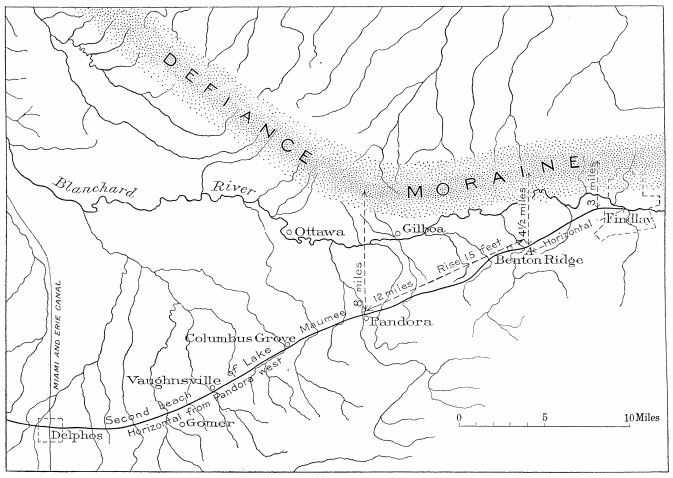


FIGURE 4.—Map showing relation of the second or middle Maumee beach to the Defiance moraine west of Findlay, Ohio.

It was pointed out that the middle beach appears to be superposed on the rampart ridges between Pandora and Benton Ridge and that it there rises very perceptibly. Westward from Pandora to a point about 8 miles west of Delphos, which is as far as mapping has been completed, the middle beach appears to be horizontal, the altitude on its crest varying from 771 to 777 feet, the lower figures being apparently on parts not fully developed. Northeastward from Pandora the beach appears to rise.

Northeastward from Pandora the middle beach (see p. 340) seems to be continued in the strong but somewhat bent and broken line which rises from Pandora to Benton Ridge and Findlay. Mr. Leverett[1] describes it as follows:

> Between Pandora and Findlay the beach is very strong as far as Benton Ridge, there being usually a bank 10 to 20 feet high, capped by gravel several feet in depth. From near Benton Ridge to Findlay the bank is but 6 to 10 feet high and the deposits are rather sandy. This part of the beach borders a narrow bay south of the Defiance moraine, and in view of its situation is remarkably strong.

[1]Mon. U. S. Geol. Survey, vol. 41, 1902, p. 729.

More recently, with the topographic maps in hand, the writer reexamined the district and received the same impression as to the continuity of the middle beach from Pandora to Benton Ridge and Findlay.

The Survey's topographic maps show that the rise does not extend all the way to Findlay but that several small parts of the crest rise to or a little above 790 feet above sea level a mile or more west of Benton Ridge and that an increasing proportion rises to this height farther east. Some of the beach crest to the west of Benton Ridge is mainly sand, but that to the east is largely gravel, though of sand in some places and clayey gravel in others. About 11/2 miles east of Benton Ridge the crest is mainly above 790 feet, but it seems to rise no higher farther east, continuing about the same to the bend 11/2 miles west of the courthouse in Findlay. Eastward from this point the crest appears to decline a little, but apparently only because it is more faintly developed.

From Pandora to Benton Ridge, and less conspicuously from Columbus Grove to Pandora, the middle beach has a mildly scalloped front made up of a series of curved sections convex toward the north-northwest and joined end to end. The west halves of most of the scallops trend southwest and are in fact parts of one of the preexisting rampart ridges changed only a little by the waves, in some places by erosion, but generally by an overcoating of sand and gravel. The east halves of the scallops trend east obliquely across the courses of the rampart fragments and are parts of a new-made ridge constructed by the waves to bridge the gap from one rampart ridge to the next one east. Where the newly built section meets the next older rampart there is a reentrant angle of the shore—a wave-built beach running east and abutting against the face of an older clayey rampart running northeast. It was in this way that the middle Maumee beach acquired its scalloped form east of Columbus Grove. Where the trend in this interval is northeast to southwest the main body of the ridge of the middle beach is generally one of the older rampart ridges. At many places, especially on the inner slope, the clayey gravel may be seen. For 2 miles northeast from St. John's Church and for 3 miles southwest from Benton Ridge the beach seems clearly to be superposed on a rampart ridge. At the latter place especially this relation seems certain, for at the southwest, where the middle Maumee beach turns away to the west, one of the finest of the rampart ridges runs on southwest behind the middle beach in perfect continuity in its precise trend from Benton Ridge.

The whole rise of the middle beach appears to be between Pandora and a point 11/2 miles east of Benton Ridge—a distance of about 12 miles and a rise of 15 feet, or from an average altitude of about 775 feet to a little more than 790 feet above sea level. The rate of rise is therefore a little more than 1.2 feet to the mile.

To the meridian of Pandora, 16 miles on a line directly west from Findlay, the Defiance moraine runs a trifle south of west, but north of Pandora it turns northwestward. On a line directly north from Pandora the crest of the moraine is 8 miles away, and north of the bend of the beach 2 miles west of Findlay it is scarcely 3 miles away. This part of the beach, therefore, is not exactly parallel with the crest of the moraine, but in 16 miles it draws only 5 miles nearer, or from 8 to 3 miles. From Ottawa Creek, a mile east of Benton Ridge, to Findlay the beach is more nearly parallel with the moraine than it is farther west, and this part is apparently about horizontal at a little above 790 feet.

Two to three miles north of Gilboa faint and fragmentary indications of a shore line appear along the crest of the moraine for about 4 miles at an altitude a trifle above 790 feet, the precise altitude being difficult to determine because the deposit is mostly fine sand and somewhat wind blown.

Mr. Leverett's studies on the Maumee beaches on the inner or northern slope of the Defiance moraine show only the middle and lowest Maumee beaches to be present. The Defiance moraine thus appears definitely to limit the eastward extension of the highest beach on this side of the lake and at the same time to draw the middle beach up out of the horizontal plane. This is on the supposition that the ice front was resting on the moraine when the inclined section of the beach was being made.

In general the relation of the inclined part of the beach to the moraine and to the ice front resting on it is what might be expected as a normal result of the attraction of the ice sheet, but in detail some rather serious difficulties present themselves. As pointed out above, the inclined part of the beach approaches the front of the moraine on an oblique line, rising 15 feet in 12 miles. But the true amount of deformation of the old water plane is found by measuring it on the line of maximum deformation, which in this case would be on a line normal to the ice front.

If the beach rises from Pandora 15 feet on an oblique line ending 3 miles south of the moraine, the same amount of ascent would take place in a shorter distance on a line normal to the ice front. Pandora is 8 miles south of the crest of the moraine. The altitude of the beach 3 miles south of the moraine on this line ought to be the same as it is at the end of the oblique line the same distance from the moraine, the two localities being so close together and there being no change in the value of the larger factors of deformation. But if this be true the beach would rise the observed 15 feet in going 5 miles north from Pandora, or at the rate of 3 feet per mile.

If the plane of the rising beach is carried up to a position in contact with the front of the ice represented as resting on the crest of the moraine, the rising beach must be followed 3 miles farther north, and even if its rate of rise is assumed to continue without increase it is necessary to add 9 feet to the 15 feet of rise already found. But, theoretically, the rate of rise should increase toward the ice. It seems certain, therefore, that this much additional rise must be assumed on a line going north from Pandora, and this would lead one to expect the beach on the crest of the moraine (supposing the moraine high enough to have the beach recorded upon it) to have an altitude of at least 800 feet. But the end of the line running 8 miles north from Pandora rests on the sandy belt at an altitude of 790 to 795 feet. Another difficulty arises from the fact that the inclined part of the beach appears to come to a sudden end at Pandora, the beach being horizontal beyond that point. It would seem as though deformation by such a cause would give the water surface a gradual and progressive diminution of inclination in going away from the ice front, one which would take the form either of a parabola or of a hyperbola when seen in vertical section. The facts in this locality indicate that if ice attraction is the cause of the deformation it drew the water surface up 25 or 30 feet in 8 miles from the edge of the ice, but had no appreciable effect at a greater distance. In other parts of the area of horizontality, however, there are facts which may be regarded as evidences of the attraction of the ice sheet at a distance. (See pp. 346-348.)

Application of theory.—On the assumption that the ice sheet maintains a thickness of 10,000 feet to its edge (p. 342) Woodward calculates that the water surface at the edge of the ice would be drawn up 573 feet and would slope away at a rate of 1 foot to the mile. On the assumption that the ice sheet slopes 18.34 feet per mile, which is in all probability less than its actual slope, he calculates that the water surface at the edge of the ice would be drawn up 326 feet. The observed effect, if rightly stated above, is less than one-tenth of this amount.

When it is considered that the Maumee ice lobe protruded considerably forward from the general front of the ice sheet, that it was in all probability a relatively thin body, and that by the time the ice front had retreated to the Defiance moraine the thickness of the ice sheet at its center was probably not over 5,000 feet, it is easily seen that the real values for the effects of ice attraction in the Great Lakes region are more likely to be of the order of magnitude of the slight deformation indicated by the features found west of Findlay than by the much larger values found by Woodward.

On a rough calculation, based on Woodward's assumption of an ice cap covering the northern hemisphere completely down to the thirty-eighth parallel of latitude and having a uniform thickness to its edge of 10,000 feet, it seems probable that the combined mass of all the actual ice sheets in the northern hemisphere, even at their maximum extent, was not more than one-fiftieth of the mass of Woodward's assumed ice cap. When the ice sheets had dwindled to the stage marked by Lake Maumee, this combined mass was scarcely more than one seventy-fifth or perhaps one one-hundredth. The smallness of these values is due largely to the fact, now well established, that there was no polar

ice cap, like that assumed by Woodward, but that the real ice sheets were relatively local and restricted bodies, spreading from centers of growth in Labrador, Keewatin, Patricia, British Columbia, and Scandinavia.

In thinking of this problem it is necessary to remember that most of the ice Woodward reckoned upon was far away—half of it being distant over 90° of longitude and more than 38° of latitude—and had therefore a relatively small effect on the total result. It was the ice that stood near the lake that had the greatest effect and constituted the chief factor of deformation. It is not surprising, therefore, that such small values have been found for its attraction.

The features of this district bearing on the attraction of the ice sheet and its effect in deforming the lake surface are suggestive and in a general way appear to be confirmatory, but they fail in some important respects to accord with expectation based on what is believed to be sound theory.

DEFORMATION EAST OF DEFIANCE MORAINE,

As noted above, the limits of Lake Maumee in the region east of the Defiance moraine appear to correspond in altitude with the middle beach of Lake Maumee west of that moraine. It was formerly supposed that this beach extended about to Ashtabula, Ohio, without measurable tilting or deformation. But since the making of the topographic maps it is found that beginning about at Cleveland this beach makes a relatively rapid rise to the vicinity of Mentor and Painesville. The distance is 25 to 28 miles and the rise about 10 feet, an amount which seems to accord fairly well with deformation found between Pandora and Findlay.

The situation is much the same as that in the district just discussed, except that the contemporary position of the ice front is not accurately known. At the time of this beach the margin of the ice lobe in Lake Erie probably ran nearly parallel with the south shore and not a great distance from it.

DEFORMATION IN FORT WAYNE DISTRICT.

In discussing the first Maumee beach Mr. Leverett[1] states that near the vicinity of the Fort Wayne outlet this beach stood at 775 to 780 feet. Near the Ohio-Michigan State line several observations unite in giving the beach an altitude about 26 feet higher—at West Unity, Ohio, 801 feet, at Fayette 798 feet, and at Fairfield, Mich., 799 feet, these points all being close in front or west of the Defiance moraine. Northeast from Fairfield, on the inner or east side of the Defiance moraine, the altitude of this beach seems to be slightly lower.

Although this district lies within the “area of horizontality” and is therefore important in the investigation of this question, topographic mapping has not yet been extended into it and it seems too soon to discuss it. Other localities in the area of horizontality are found on the shores of Lake Michigan southward from Grand Haven, but accurate surveys of them have not been made.

Several other localities seem at first to afford promising places for studying the effects of ice attraction. One is the highest Maumee beach between Birmingham and Almont or Imlay, Mich.; another is the Whittlesey beach from Richmond to Applegate or Carsonville, Mich.; another is the Whittlesey beach between Dunkirk and Alden, N. Y., and still others are in Ontario. But all of these are in the region of stronger uplift from other causes and it would seem hardly profitable to attempt to unravel their complex phenomena.

ATTRACTION AT MODERATE DISTANCES FROM THE ICE.

Variations of altitude other than those described above (p. 344) for the Maumee beach are noticeable. Between Leipsic and Berea, Ohio, a distance of 115 miles, the middle beach rises about 10 feet, or about 0.08 foot to the mile. Variations like this, amounting to 10 or 20 feet in 100 miles or more, probably occur in other places. It seems quite probable that such a rise occurs between the head of the outlet near Fort Wayne and Findlay in connection with the highest beach. Mr. Leverett found the hooked spit on the east side of the Sixmile Channel at New Haven, Ind., to have an altitude of 786 feet, its crest being 2 or 3 feet higher than the average crest of the highest beach. It seems probable, therefore, that the highest beach rises in this interval from 783 or 784 feet to 790 feet, the distance being about 75 miles and the rate of rise, therefore, about 0.1 foot to the mile. The same gentle rise of the highest beach probably occurs between the head of the outlet near Fort Wayne and some point northeast of Bryan, Ohio, but accurate data for its determination are not now at hand. Again, from the vicinity of Fairfield, Mich., to Birmingham the beach appears to rise between 5 and 10 feet, the distance being about 65 miles. But in this last area there may be some complication.

[1]Mon. U. S. Geol. Survey, vol. 41, 1902, pp. 724-725.

The long, gentle slopes of the Maumee beaches, 0.1 foot or less to the mile, may represent the effect of ice attraction at a distance from the front. It is an extremely small deformation, but it seems more nearly what one would expect from a relatively small, thin ice lobe, like that related to Lake Maumee at the stages in question, than the larger deformation of 1 foot to the mile in the case worked out by Woodward.

Near Findlay and near Cleveland and at perhaps two or three other localities the beaches seem to record a relatively short, steep rise of the water plane at the immediate front of the ice. The long, gentle slopes of the beaches described here seem to represent the effect of ice attraction at a distance and stand in obvious contrast to the other effect. Considered as results of ice attraction, both of these phenomena seem normal in their distribution with regard to the ice sheet and with regard to each other.

It would seem utterly hopeless to look for such small effects of deformation as the long, gentle slopes

described above in areas where other causes of deformation have operated. Only in the so-called area of horizontality, where other causes of deformation seem not to have operated, or to have been of a still smaller order of magnitude, could such slight deformations be recognized.

In the area of horizontality all the shore lines below the Maumee beaches, except two of the Arkona beaches which converge slightly southward, appear to be perfectly horizontal; that is to say, their variations of altitude appear to be so small that they fall well within the limits of variation which attend the formation of all beaches on account of the varying height of the deposits from point to point along the shore. This fact has in it something of the quality of confirmation of the supposition that it was ice attraction which produced the two peculiar deformations of the Maumee beaches described above, for the ice front was not near by when those later beaches were formed at lower levels, and the ice attraction can hardly be considered as an appreciable disturbing factor. The first and second Arkona beaches appear to merge southward in one, only two ridges occurring in Ohio. (See p. 372.) The cause of this relation is obscure and seems hardly referable to ice attraction.

Some doubt, however, remains as to whether the two classes of deformation ascribed to ice attraction are, in fact, represented in an unmixed way in the phenomena described. Certain other factors, such as strong winds, may have operated to raise or lower the water of the lake and with it the zone of wave action. The deformations that produced the long, gentle slopes were not much greater than the disturbances of lake level observed in recent years on Lake Erie. The wind effects, however, are not distributed like the deformations, for it is of record that a heavy northeaster has raised the lake at Toledo about as much as a heavy southwester has at Buffalo.

The main part of the large deformation of the old shore lines farther north is ascribed by most students to resilience following depression by the weight of the ice sheet. But when the ice sheet of the Wisconsin invasion was at its maximum it reached 50 to 100 miles beyond the southern shores of Lakes Maumee and Chicago and covered all of the area of horizontality, so far as its limits are indicated by the beaches.

Though this area was not subjected to the maximum ice weighting, it was nevertheless subjected to very considerable pressure—enough to lead one to expect at least some small resilience on its removal. But the distribution and relations of the small deformations observed within the area of horizontality do not appear to be in accord with such a cause. Furthermore, if there has been even a very slight deformation due to ice weighting and resilience it could hardly fail to complicate and obscure in greater or less degree the deformation due to ice attraction. All the deformation found in this area seems to accord better with ice attraction than with any other cause that has been suggested.

It is therefore concluded, provisionally, that the land in the area of horizontality has in fact remained practically unaffected by the great deformations which uplifted and tilted the region farther north. This area appears to have remained like a steady point while the region north of it was undergoing large changes of altitude and attitude. The area of horizontality may be used, provisionally, therefore, as the measure, not merely of relative movements, but of the absolute movements of elevation which have affected the deformed area farther north since the beginning of Lakes Maumee and Chicago. But it is not certain that this use has any application to times earlier than the beginning of these lakes.

The first and second Arkona beaches show a slight convergence toward the south in the northern part of the area of horizontality. In the vicinity of Birmingham the first Arkona beach appears to be 6 or 7 feet above the second, and this relation continues without noticeable change to the vicinity of Ypsilanti. Southward the second Arkona beach seems to rise gradually until the interval between it and the first is only 2 or 3 feet, and it finally pinches out entirely, so that in Ohio one beach appears to stand in the place of the first and second. This phenomenon may be due to an entirely different cause from that which affected the Maumee beaches, but it is of about the same order of magnitude. Probably it could not have been caused by ice attraction alone. It appears more likely to have been due to a very gentle uplift and tilting at the north following a lowering of the lake by a cutting down of the outlet. The outlet being at the north, this movement may have backed the water at the' south up to or over the first beach. If due to deformation by some other cause these facts modify the estimated effect of ice attraction on the Maumee beaches south of Birmingham.

RELATION OF MAUMEE BEACHES TO MORAINES AND OUTLETS NEAR IMLAY, MICH.

So long as the Fort Wayne outlet remained continuously active the history of Lake Maumee was very simple. But when the oscillating ice front had retreated as far as northeastern Lapeer County, Mich., the relations began to be complicated. The first opening of an outlet near Imlay probably occurred on the retreat of the ice front immediately preceding the making of the Defiance moraine. Though no positive proof of such an opening is at present available, one is suggested by the character of the Defiance moraine where it passes from southwestern Almont Township into eastern Attica Township. It seems certain that an outlet past Imlay was opened at the retreat next preceding the Birmingham moraine, the low, slender character of this moraine from Romeo to Imlay being apparently due to the presence of this outlet river close along the ice front. (See pp. 283-284.)

From a point a mile or two southeast of Dryden the Defiance moraine begins to weaken and from the

northwest corner of Almont Township northward about 4 miles to Belle River it shows the same kind of modification and weakening that characterizes the Birmingham moraine north of Romeo.

If an outlet was opened before the building of the Defiance moraine it was closed when the ice readvanced to that moraine. At the next backward oscillation a new outlet was opened through the same district and was in turn closed by the readvance to the Birmingham moraine. Nothing definite is known concerning the first of these outlets, but in all probability the Lum and Rochester channels are parts of the second one.

At the next back step of the ice front another outlet was opened, apparently at a somewhat lower level, and it was during the activity of this outlet that the lowest beach of Lake Maumee was made. The next step of readvance of the ice did not close the outlet but pushed it up the slope to the place where the Imlay outlet channel is now found, close in front of the Imlay moraine and 20 feet higher than the lowest beach. The location of the outlet channel at the time of the lowest beach is not definitely known. In southeastern Lapeer County and in Genesee County it appears to have been overridden and destroyed, but it was very probably followed by the Imlay outlet river from near North Branch to the narrows above Columbiaville. This may account for the apparent greater depth and later aggradation of this part of the Imlay channel.

Glacial Lake Lapeer, a small lake in central Lapeer County, existed during the building of the Defiance moraine. Silverwood glacial lake, in northern Lapeer County, appears to have been formed at the time of the Imlay or perhaps of the Goodland moraine. It stood at about 860 feet altitude near Silverwood and received the Silverwood and Fostoria outwash aprons. It may be that a closing of the outlet in Genesee County by the readvance to either the St. Johns or the Fowler moraine held it in place. Its relations and correlative moraines, however, are not definitely known.

During the remainder of the life of Lake Maumee, while the Goodland, Berville, Mount Clemens, Emmett, and Yale moraines were being made, the oscillations went on without affecting the level of the lake so far as known. Perhaps at the retreat following the Yale moraine a new outlet, through the East Dayton channel, may have been opened just before the final fall of the waters to a much lower level; but the relations and connections of this channel are also still problematic.

ICE BARRIERS OF LAKE MAUMEE.

In its earliest beginnings Lake Maumee was confined to a small area in Indiana and northwestern Ohio and its ice barrier was then the front of the Huron-Erie or Maumee ice lobe. The subordinate members of the Fort Wayne moraine are faintly developed between the main Fort Wayne and Defiance moraines, but there are several of them and they mark as many resting places of the ice barrier, each probably marking the culmination of a slight readvance. During the time of the Defiance and Birmingham moraines the Fort Wayne outlet was still active and the relation of the ice barrier to the lake continued to be extremely simple. But when the oscillations opened outlets on the “thumb” and closed them by readvances the level of the lake was probably affected by nearly every movement of the ice front.

Until the ice had retreated about to the Mount Clemens moraine the ice barrier presented a single lobate front, for the Huron and Erie ice lobes were probably still welded together along their line of contact in southwestern Ontario. The crease between them, however, had become accentuated. Ontario Island,[1] which had probably begun to be uncovered at the time of the Defiance moraine, had now become much enlarged and the ice lobes were on the point of complete and final separation. The position of the moraines in Michigan and southwestern Ontario seems to indicate that the separation occurred just after the building of the Mount Clemens moraine.

During the closing stages of Lake Maumee the ice front stood on the Yale moraine or possibly somewhat farther north, and the correlative of this in the Lake Erie basin is probably found in one of the moraines immediately preceding the Gowanda moraine of western New York. This is in harmony with the correlation of certain gravel deposits at Girard and Fairview, Pa., with the lowest beach of Lake Maumee, and it is also in harmony with the very clear correlation of the Alden moraine of western New York with a late substage of the Port Huron morainic system of Michigan. Three positions of the western barrier of Lake Maumee are shown in figure 6 (p. 370).

At its close, therefore, Lake Maumee, like all the later Huron-Erie glacial lakes, was retained by two separated ice barriers, one in the Huron basin and the other in the Erie basin. At this time Lake Maumee had a short stretch of northern land shore in the vicinity of London, Ontario. The length of this, however, could not have been great, and it endured for only a relatively short time before the lake waters fell to a lower level. A faint shore line marking this last stage of Lake Maumee may be looked for in the vicinity of London, though none has yet been reported.

CORRELATIVES OF LAKE MAUMEE.

As nearly as can be determined by a study of correlative moraines in. the different lake basins, it seems almost certain that Lake Chicago had its early beginnings at about the same time as Lake Maumee, but such evidence as is now available indicates that Lake Duluth, in the western end of the Lake Superior basin, began later. Toward the close of the existence of Lake Maumee Lake Saginaw was formed in front of the Saginaw lobe. It received the overflow of Lake Maumee but did not attain large size at this time.

As the waters fell to the level of the Arkona beaches a transient precursor of Lake Whittlesey must have been formed, but its duration was probably very brief.

[1]The uncovering of Ontario Island is described by the writer in The moraine systems of southwestern Ontario: Trans. Canadian Inst., vol. 10, 1913, pp. 37-39, with map.