DESCRIPTION OF THE ANN ARBOR QUADRANGLE.

By I. C. Russell and Frank Leverett.*

GEOGRAPHY.

CIVIC RELATIONS.

The Ann Arbor quadrangle, embracing an area of 884.85 square miles, is in the southeastern part of the Southern Peninsula of Michigan, the city of Ann Arbor being near its geographic center. It is bounded by parallels 42° and 42° 30′ north latitude and meridians 83° 30′ and 84° west longitude, and comprises a large part of Washtenaw County and small adjacent portions of Livingston, Oakland, Wayne, Monroe, and Lenawee counties.

The first settlement within this quadrangle was made in 1809 by French traders, who established a post on the site of the present city of Ypsilanti, that being a point at which the Indian trails from a wide extent of country intersected. In 1811 about 2500 acres were patented to these traders in accordance with an act of Congress, and the survey of these claims antedated the rectangular land survey begun in 1816, a fact that accounts for peculiarities of boundary lines and absence of section lines in Ypsilanti and the district immediately south and west of that city. By the treaties of 1819 and 1821 all the lands in this region were thrown open to settlement, and in 1823 a number of English-speaking families built houses on the banks of the Huron immediately below Ypsilanti. During the following year a settlement was started at Ann Arbor. Within this quadrangle there are now two cities, Ann Arbor and Ypsilanti, and seven incorporated villages, Pinckney, South Lyon, Dexter, Saline, Milan, Clinton, and Tecumseh. In addition to these there are over 40 smaller villages and hamlets.

According to the census of 1900 the quadrangle had then a population of about 57,000, of which 14,509 were in Ann Arbor and 7378 in Ypsilanti, while the seven incorporated villages comprised a population of 7220, leaving nearly half the inhabitants in the rural districts and in villages and hamlets not separately enumerated.

The cities and nearly all the villages are on the banks of streams. These streams are not navigable, but the location of the early settlements on them was determined by the water power they afforded for gristmills and sawmills—power which has been utilized later for other manufacturing establishments. Within the past few years the scenic attractions and recreation afforded by the lakes in the northern part of the quadrangle have become factors in peopling that region.

TOPOGRAPHY.

GENERAL STATEMENT.

The topography of the present surface is strikingly different from that of the surface of the bed rock. It is the product of glacial deposition, repeated several times, supplemented to a slight degree by the action of lakes, streams, and the wind. The latest and perhaps some of the earlier glaciation resulted from a westward movement of ice from the basin of Lake Erie and the southern end of Lake Huron. This glacial mass covered the entire quadrangle except its extreme northwestern corner, which was occupied by ice moving southward from the Saginaw basin. These two ice lobes are known as the Huron-Erie and the Saginaw lobes. The glacial deposits produced by them are very thick and are so massed that even the salient features of the underlying preglacial surface are completely concealed.

RELIEF.

Conspicuous features.—The glacial features that give variety to the surface—such as moraines, kames, eskers, outwash aprons, basins, till plains, gravel plains—are noted and described in the discussion of the glacial geology, and therefore attention is here directed only to certain strongly marked topographic belts. These belts, named in order from east to west, are (1) the lake plain; (2) the morainic system on the western border of the lake plain; (3) the intermorainic strips with nearly plane surfaces; (4) the interlobate moraine, with its included gravel plains, lying between the Saginaw and Huron-Erie ice lobes.

The lake plain.—The lake plain embraces the southeastern part of the quadrangle. It extends as far northwest as the 800-foot contour, which follows approximately the highest beach of a large glacial lake, discussed below. This plain occupies parts of several counties in southeastern Michigan and a still larger area in northwestern Ohio, bordering Lake Erie, toward which it gradually slopes. The sandy portion of its bed is characterized by low dunes, 5 to 20 feet high, but the clayey portion is remarkably smooth. Beaches occur at various levels, their altitudes corresponding to those of several outlets opened for the discharge of the lakes by the withdrawal of the ice sheet. Although these are inconspicuous ridges, at few places reaching a height of more than 15 feet, yet their form and continuity attract attention, and from the earliest days of settlement they have been recognized as old lake shores. These beaches were mapped in part by the First Geological Survey of Michigan, prior to 1840.

Morainic ridges.—Immediately back of the lake plain lies a system of morainic ridges running from the northeast to the southwest corner of the quadrangle and occupying a belt 8 to 12 miles wide. Valley-like depressions between the ridges serve as convenient courses for streams, which have in consequence assumed a trellis-like arrangement.

Three more or less distinct moraines appear in this system, of which the westernmost is far more prominent than the others. This moraine includes the highest points within the quadrangle, one exceeding and several approaching 1100 feet in altitude—indeed, much of the land that stands above 1000 feet. In the southwestern part of the quadrangle this high moraine constitutes the divide between the tributaries of the Huron and the Raisin, while in the northeastern part it separates the waters of the Rouge from those of the Huron. The Huron and Raisin find passage southeastward through deep gaps in this ridge, and farther along in their courses pass through similar gaps in the lower ridges, to continue southeastward to the lake plain and thence to Lake Erie. The most prevalent type of morainic topography in this system is the swell and sag, in which there is a gradual rise from sag to swell and very little sharp undulation. At certain points, however, there are knobs and basins with steep slopes. Most of the sharpest knobs are gravelly hills known as kames.

The intermorainic strip.—Outside the belt of moraines just described, in the interval between it and the interlobate system of moraines and gravel plains, lies a long area that is rather difficult to describe because of the great variety of its features. Parts of it are flat surfaced, or nearly free from knolls or ridges, while other parts present sharp undulations, as strongly marked as the knolls and ridges of the moraines though not so systematically related. This area contains also a large number of marshy depressions, which break up the continuity of the plainlike tracts in which they lie. Some of these are one-fourth to one-half mile wide and several miles long and many of them lie in the courses of streams and form parts of river systems. A chain of gravel ridges known as the Lima esker and several kames appear in this strip. The topography of this district apparently owes its irregularity to variations in rate of deposition and in drainage at the margin of the Huron-Erie ice lobe during its recession from the interlobate moraine to the first well-defined moraine southeast of it. In addition to the features mentioned, this district is traversed by several lines of glacial drainage that lead northwestward into the interlobate belt. These are much broader than the depressions just noted, being in some places more than a mile wide, and are filled with flat-surfaced deposits of sand and gravel left by the streams that formed them.

The interlobate moraine and included gravel plains.—A conspicuous system of moraines appears in the northwestern part of the quadrangle, north of a line from South Lyon, passing Whitmore Lake, to Fourmile Lake. The surface of this morainic system is much more irregular than that of the system just considered, sharp knolls 100 to 200 feet in height being here closely associated with basins, some of which, now occupied by lakes, exceed 100 feet in depth. This morainic system is traversed by sandy plains that mark lines of glacial drainage and with its included lakes and streams it forms part of a great interlobate tract developed along the junction of the Saginaw and Huron-Erie ice lobes. Its northwestern border is beyond the limits of the quadrangle.

DRAINAGE.

Streams.—The streams of this quadrangle flow either directly or indirectly to the western end of Lake Erie. A large part of the quadrangle is drained by Huron River and the remainder chiefly by Raisin River and its tributaries.

Huron River, a stream about 150 miles in length, flows southward from its source in Big Lake, Oakland County, to the northern edge of the quadrangle, and then makes a curve southwestward, southward, and southeastward through the quadrangle, and continues in a southeastward course to its mouth at the extreme head of Lake Erie. Nearly all the tributaries of Huron River are small, the most important lying within the limits of this quadrangle.

Raisin River, a stream perhaps 160 miles in length, drains, with its tributaries, much of the southern end of the quadrangle, though the main stream traverses only its southwestern corner. From the source near Jerome, in northern Hillsdale County, it flows north of east into Washtenaw County, a distance of 40 to 45 miles. Near the western limits of the Ann Arbor quadrangle it swings around to a southward course across the southwest corner of the quadrangle and continues nearly to the Ohio State line, where it again takes an eastward course, flowing into Lake Erie.

Saline River, the most important tributary of Raisin River within this quadrangle, has its principal source in Columbia Lake a few miles west of the village of Saline, and its mouth just outside the southern limits of the quadrangle. The stream is about 45 miles long and in its entire course descends about 230 feet, the altitude of Columbia Lake being 864 feet and that of the river's mouth being about 634 feet.

Macon River embraces a widely branching drainage system which gathers the waters from a district west of Saline River, in the southwestern part of the quadrangle, and joins Raisin River within a mile above the mouth of Saline River. The sources of the several headwater branches are at altitudes of 800 to 850 feet, so that the stream makes a descent of nearly 200 feet in reaching Raisin River. Both the streams meander considerably, the distance from source to mouth probably exceeding 30 miles.

Swan Creek, Sandy Creek, and Stony Creek (with its tributaries Paint Creek and Sugar Creek) drain a small area in the southeastern part of the quadrangle, and flow directly into the western end of Lake Erie through a district lying between Huron and Raisin rivers.

Rouge River, a stream entering Detroit River near the southern limits of the city of Detroit and draining a large part of Wayne County, also drains a narrow area along the eastern border of the northern half of the Ann Arbor quadrangle.

Lakes.—Within the limits of the quadrangle there are nearly 150 small bodies of standing water which occupy basins of sufficient depth to be debarred from ready drainage. Some of these bodies are without outlet; others discharge to streams through bordering swamps with no definite channel of outflow; but, as may be seen by the topographic map, most of them have definite outlets, and a few stand in the course of streams. Nearly all of these are termed lakes, and more than 50 of them have received names. These do not include the bodies of water held in by artificial dams and called mill ponds, nor those which have become extinct, for several marshes mark the site of old water bodies whose basins have become so nearly filled with peat, marl, and sediment that they are no longer mapped as lakes.

Of the lakes indicated on the Ann Arbor topographic sheet 134 lie within the area drained by Huron River, and only 11 in the portion drained by the Raisin and its tributaries, Saline and Macon rivers; while none occur in the portion drained by Rouge River, Stony Creek, Swan Creek, and Sandy Creek. Most of them are found in the northwestern part of the quadrangle and there are none on the plain in the southeastern part, though that plain, as already indicated, was for a long time covered by the waters of great glacial lakes. The lakes abound in the part of the quadrangle where the irregularities of surface are greatest, and the flatness or regularity of the surface in the southeastern part accounts for their absence there. Few of the lakes cover an area of a square mile, and most of them cover less than one-fourth of a square mile. Several of those which are named fall within the limits of a 40-acre lot; those without names have ordinarily an area of but 5 to 10 acres, though some cover 40 acres or more. Few of the lakes have been systematically sounded to determine maximum depths, but enough soundings have been made to show that even some of the smaller lakes are 50 to 60 feet deep, and that a few have depths of more than 100 feet. Nearly all the lakes are so deep that they are not only protected from extinction by artificial drainage but also from early filling by sediments and organic growths and precipitates. They will therefore continue to be attractive features in the scenery of this region for hundreds and probably thousands of years.

GEOLOGY.

BED-ROCK SURFACE.

General statement.—The bed-rock surface of the Ann Arbor quadrangle was completely covered by glacial deposits and is now exposed only at a quarry in the southeast corner, where the rock is reached by stripping off a thin sheet of drift. Numerous wells, however, distributed widely over the quadrangle, furnish sufficient information in reference to the bed-rock surface to warrant a general statement concerning its topography. The altitudes of the bed-rock surface at points reached by wells are shown in fig. 1.

The Erie lowland.—In the southeastern part of the quadrangle the rock surface stands not far from 600 feet above sea level and is composed of several rock formations of dissimilar composition, the Monroe, Dundee, Traverse, Antrim, Berea, and Coldwater. (See the generalized section, fig. 2, p. 2.) These several formations appear to have been sufficiently beveled off at their outcrops to form a peneplain—an extensive lowland bordering Lake Erie, covering several counties in southeastern Michigan and northwestern Ohio, and extending westward across northern Indiana into Illinois—which may appropriately be termed the Erie lowland. The northwestern edge of this lowland, as indicated by altitudes of bed-rock surface given in fig. 1, crosses the Ann Arbor quadrangle near a

*The general geology, mineral waters, and marl deposits are described by I. C. Russell; the topography and drainage, Quaternary geology, and water resources by Frank Leverett; the peat deposits by Charles A. Davis; the Paleozoic history by E. M. Kindle. The Michigan State Geological Survey has freely given its records and assistance, which have been of great service, particularly in connection with the account of the peat deposits.

line running from Tecumseh northeastward past Ann Arbor and leaving the quadrangle near its

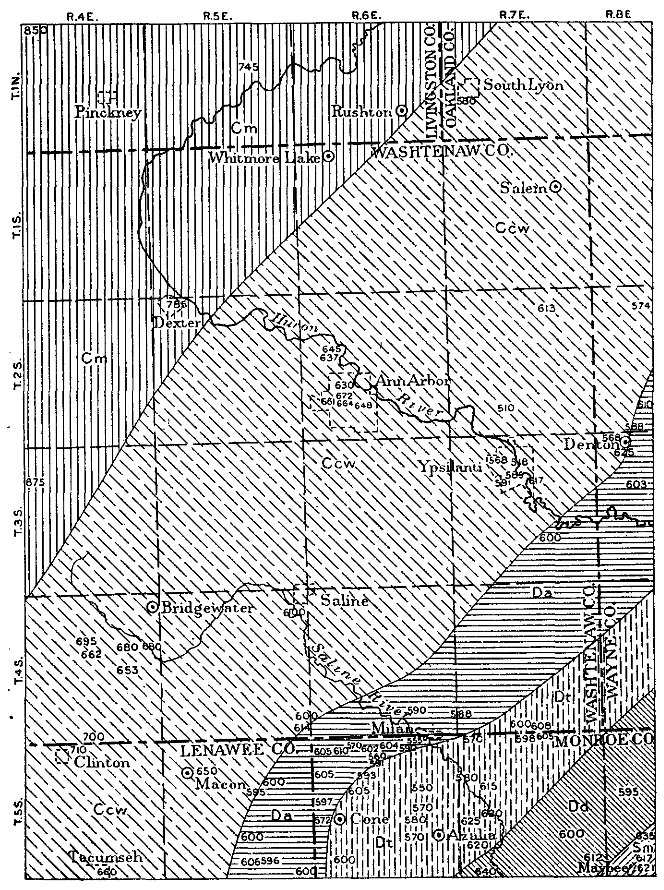

FIG. 1.—Sketch map of Ann Arbor quadrangle, showing outcrop of Paleozoic formations beneath the drift and altitudes of the bed-rock surface.

Sm, Monroe formation; Dd, Dundee limestone; Dt, Traverse formation; Da, Antrim shale; Ccw, Coldwater shale with Berea sandstone at base; Cm, Marshall sandstone. Figures give altitude of bed rock in wells.

northeast corner. Within a few miles west of this line there is a rise of about 200 feet to a table-land in which the Marshall sandstone forms the bed-rock surface.

The Marshall table-land.—This table-land covers several counties in southeastern Michigan and runs northeastward into Huron County along the outcrop of the Marshall sandstone and other sandstones of Carboniferous age. In an area comprising a few townships near the corners of Jackson, Hillsdale, Calhoun, and Branch counties the rock surface rises to altitudes of 1000 to 1150 feet above sea level, but generally it lies below 900 feet, and on passing northward into Huron County it gradually grows lower, though holding a height of 750 feet as far north as that county.

Preglacial drainage lines.—In the above statement the preglacial drainage lines have been disregarded. Borings indicate that the main preglacial valleys were cut to levels about 100 feet below the Erie plain (or to not far from 500 feet above sea level), though many of the tributary valleys were cut only 50 to 75 feet into this lowland. The valleys in the Marshall table-land were cut deeper, yet their floors stand at a higher level, being near the sources of the streams. As would naturally be inferred and as is indicated by the borings, the valleys discharged eastward from the table-land across the lowland, and appear to converge toward Detroit, where the rock surface is but little above 450 feet. The borings or data concerning the valleys are, however, too few to warrant even a general mapping of the main preglacial drainage lines of this region.

Effect of glaciation.—Attention has been called to the presence of broad, very shallow troughs in the rock surface in Monroe and Wayne counties, which follow the belts of outcrop of the weaker rock formations, and the suggestion has been made that these troughs were developed by the ice at a time when its movement conformed very nearly to the strike of the rock formations. (See "Ice work in southeastern Michigan," by W. H. Sherzer, Jour. Geol., vol. 10, 1902, pp. 194–216.) The troughs are much broader and shallower than the preglacial drainage lines. It may be difficult at present to demonstrate that the troughs were appreciably enlarged by the ice, since there is a likelihood that prior to the glacial epoch the weaker rock formations would have been broken down to somewhat lower levels than the more resistant formations.

SEDIMENTARY ROCKS.

GENERAL STATEMENT.

The entire quadrangle is covered by a sheet of unconsolidated material, deposited by glaciers and streams or in lakes, which ranges in thickness from about 300 feet down to a few feet. The information available concerning the stratified sedimentary rocks or geological formations lying beneath these surface deposits is derived from the records of a few deep wells, some of them outside the quadrangle, supplemented by such evidence as is furnished by the rocks of a single quarry and fragments of the underlying rocks contained in the surficial deposits.

The work of the Michigan State Geological Survey has shown that the formations present in the Southern Peninsula consist principally of limestones, dolomites, sandstones, and shales which, as is proved by fossils, were deposited in ocean waters. That is, during nearly all of the immensely great periods of time in which the rock foundations of Michigan were being laid down, the ocean occupied the area, the only known rocks not deposited in the sea being the coal beds, and possibly some of the shales associated with them, in the central portion of the Southern Peninsula. It is probable also that beds of salt and of gypsum found in certain of the formations were produced by the concentration, through evaporation, of saline matter in landlocked basins.

In geological age the youngest of the formations beneath the glacial drift belongs to the Carboniferous system. Below the Carboniferous, in normal succession, occur Devonian, Silurian, Ordovician, and probably still older formations. Beneath these stratified rocks the crystalline rocks of the Archean system are no doubt present, but these have not yet been reached by the deepest drill holes bored in the Southern Peninsula. The subdivisions of the systems just mentioned which have been recognized in the Ann Arbor quadrangle, and their places in the general scheme of geological history as determined by the State Survey are indicated in fig. 2.

System.	Formation Name.	Thickness in Feet.	Character of Rocks.
Carboniferous	Marshall sandstone.	150±	Brown, gray, and yellowish sandstone. Bands of iron concretions near base. "Second" brine horizon.
	Coldwater shale.	670–960	Light-colored, green, bluish, and gray shales, with calcareous layers and thin beds of limestone.
	(May represent Sunbury shale.)	(60)	Black, bituminous shale.
	Berea sandstone.	65	Coarse gray sandstone. "Third" brine horizon.
Devonian	Antrim shale.	145–300	Dark shale, in places black and bituminous. Contains iron pyrite, oil, and gas.
	Traverse formation.	100–600	Bluish calcareous shale and thin-bedded limestone.
	Dundee limestone.	40–160	Gray and yellowish bituminous limestone with sand and chert.
Silurian		(40–100)	Gray and drab oolitic and sandy dolomite, in part thick bedded.
	(Sylvania sandstone member.)	(100–150+)	Fine, incoherent, sparkling white sandstone.
	Monroe formation.	650–2000	Bluish to drab dolomite and bluish calcareous shale, containing anhydrite, gypsum, and salt. "Fourth" brine horizon.

FIG. 2.—Generalized section of the rocks of the Ann Arbor quadrangle, as determined by the Michigan Geological Survey for southern Michigan.

The various members of these systems of sedimentary or stratified rocks were deposited in essentially horizontal sheets of various thicknesses, ranging from a few score feet to over a thousand feet, and since their deposition have been only moderately disturbed by movements in the earth's crust which have resulted in tilting the rocks toward the central part of the Southern Peninsula. The amount of this tilting or inclination in the region occupied by the Ann Arbor quadrangle is about 35 feet per mile. In their present position the sheets of rock resemble a pile of shallow saucers, one placed within another, the one at the top, or the one last added to the series, being the coal-bearing formation of the Carboniferous. About the borders of this formation, which occupies a central geographic position, the edges of the older formations below appear at the surface in a series of concentric although irregular rings or belts. After the beds had assumed their present saucer-like form, their surfaces were eroded for a long time so that the entire area of the Southern Peninsula was planed away to a generally uniform level. This long period of erosion preceded the deposition of the present surface sheet of glacial drift. The rock surface beneath the drift in this quadrangle, as shown principally by the records of wells (see fig. 1), is a fairly smooth plain except in the northwestern part, where the presence of ancient hills and valleys is evident.

The relations of the Ann Arbor quadrangle to the Southern Peninsula in general, supplemented by records of deep wells drilled in the quadrangle, show that the rocks which would appear in this area if the covering of drift were removed range in age from Mississippian (Lower Carboniferous), represented by the Marshall sandstone, in the northwest corner, to Silurian, represented by the Monroe formation, in the southeastern portion. It is not now practicable to map accurately the boundaries of the several formations that lie beneath the mantle of drift in this quadrangle, but their positions are known approximately and are indicated on the geologic sketch map forming fig. 1.

SILURIAN SYSTEM.

MONROE FORMATION.

At only one locality in the Ann Arbor quadrangle do the rocks beneath the drift approach near enough to the surface to be quarried—at the Woolmith quarry, near Maybee, in the extreme southeast corner of the quadrangle. At this place a local uplift forms a low, domelike fold or anticline which is not fully exposed but is seemingly about one-half mile in diameter. In the quarry the beds dip about S. 65° W. at an angle of 2° to 3°. The rocks are principally magnesian limestones or dolomites, but some of them contain sand grains of a peculiar character and were formerly quarried for use as building stone and termed sandstone. The section exposed in the quarry and in part revealed by a drill hole in its bottom, reported by W. H. Sherzer (Geology of Michigan, vol. 7, part 1, 1900), is given in the next column.

The minerals calcite, celestite, and sulphur, occurring in cavities in the dolomite of the Woolmith quarry, have been deposited from solution by percolating water since the rock was consolidated. The deposition of sulphur is still going on. The crystals of celestite (strontium sulphate) in particular are remarkably beautiful and large, some of them measuring 2 to 4 inches across. None of these minerals occur in sufficient abundance to be of commercial value, although several barrels of sulphur were collected a few years ago and sold.

Section at Woolmith quarry.

[Arranged by W. H. Sherzer.]

	Feet.
1. Glacial till, a blue stony clay containing bowlders, extending downward to surface of highest bed of dolomite, which is intensely glaciated	2 to 8
2. Light-colored, laminated dolomite, mainly creamy white but blotched and streaked with brown; in places porous and cavernous owing to the solvent action of percolating water; where not weathered, soft, mealy, and gritty to the touch. On weathered surfaces stromatopora-like laminations are conspicuous; these are probably fossils resembling coral; the upper part of the bed contains molds and casts of gasteropod shells. The thickness of this bed varies, principally on account of the unequal removal of its upper portion by glacial erosion	2 to 4
3. Oolitic dolomite, dark gray in color, containing spherical grains, about 0.4 millimeter in diameter, made up of delicate concentric shells composed of minute interlocking crystals of dolomite. Small cavities contain crystals of calcite, celestite, and native sulphur. Laminated in basal portion, where irregular hummocks occur on the surface of the bed beneath	3½ to 4
4. Dolomite, varying in color from drab to brown and ranging in texture from a compact, tough, homogeneous to a cavernous and soft or rotten condition. Hummocky at the surface, the elevations several feet in diameter being composed of concentric laminæ. Large cavities contain celestite, calcite, and sulphur. At top and bottom surfaces there are laminæ of black, impure asphaltum, in connection with which stylolites due to pressure are present	1 to 2
5. Dolomite, dark brown and gray, varying toward blue; component layers from 2 to 8 inches thick, laminated with streaks of blue, gray, and brown dolomite and delicate films of carbonaceous material; compact, mostly free from mineral-bearing cavities; somewhat impregnated with petroleum; locally contains shells of the ostracod crustacean *Leperditia* and the small coiled shells of a worm, *Spirorbis*	1 to 5
6. Dolomite, dark brown, blotched with black, cellular and cavernous in texture, impregnated with petroleum; gives off a strong bituminous odor; contains casts and molds of shells. Numerous cavities, most of them elliptical, ranging in diameter from 1 or 2 inches to 3 feet, contain beautiful crystals of calcite, celestite, and sulphur. Portions of the bed are compact and suitable for building stone	1 to 3
7. Sandy dolomite, bluish, gritty, and almost a sandstone in certain layers; penetrated, especially in the upper part of the bed, by nearly cylindrical channels about 3 millimeters in diameter and several centimeters long, probably indicating the positions of algæ, and now containing carbonaceous matter and petroleum	2 to 3
8. Dolomite, highly siliceous; passing upward without a break into No. 9	3 to 4
9. Dolomite, light gray, siliceous, compact, free from seams, fracture conchoidal; occasional "glass seams" and dark streaks and grains of iron oxide detract from the value of the rock for use as building stone. Contains sand grains which, under the microscope, show secondary enlargements	16
10. Dolomite, compact, even grained, light-gray masses, thick bedded	15
11. Sylvania sandstone; reached by drill hole in bottom of quarry	50 (?)

Samples of the beds numbered 5 and 10 in the above section have been analyzed, with the following results:

Analyses of dolomite from the Woolmith quarry.

[By Eugene C. Sullivan.]

Constituents.	Bed 5.	Bed 10.
Silica (SiO_2)	1.30	1.77
Alumina (Al_2O_3)	.16	.01
Ferrous oxide (Fe_2O_3)	.20	.41
Magnesium oxide (MgO)	19.79	20.84
Calcium oxide (CaO)	31.14	29.65
Water ($-H_2O$) absorbed	.18	.12
Water ($+H_2O$) chemically combined	.57	.48
Carbon dioxide (CO_2)	45.18	46.40
Phosphoric acid (P_2O_5)	Trace	Trace
Sulphuric anhydride (SO_3)	1.15	.33
Manganic oxide (MnO)	Trace	Trace
	99.67	100.01

Each sample contained organic matter with odor of petroleum.

The Sylvania sandstone, reached by a drill hole in the bottom of the quarry, is a medial member of the Monroe formation. It is a widely extended sheet of remarkably pure white color, and is but slightly consolidated. The bed was named from the village of Sylvania, Ohio, where it is utilized for the manufacture of glass. The bed is presen in Michigan near Ottawa Lake, about 13 miles northwest of Toledo, and extends northeastward across Monroe County to Trenton, but throughout nearly all of this distance its presence is concealed by surface deposits. Its thickness increases from about 30 feet in the northern portion of Ohio to 95 feet at Trenton. The records of a well at Milan indicate that it is there 288 feet thick. (See fig. 3.) The width of its outcrop in Michigan

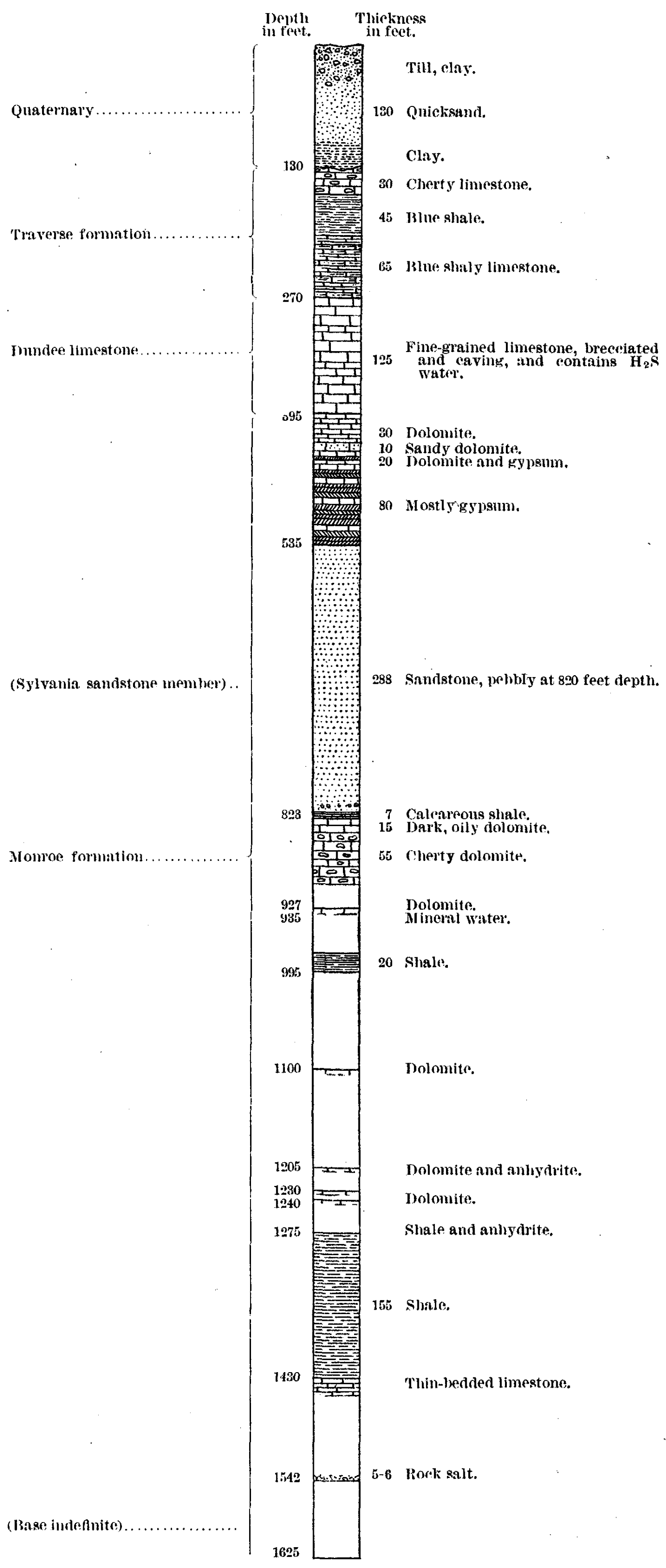

FIG. 3.—Section of well at Milan.

varies from about one-half mile to about 4 miles. From its line of outcrop the bed dips in general northwestward, and in the university campus well at Ann Arbor it was reached at a depth of 1235 feet. (See fig. 4.) The dolomite both above and below the Sylvania sandstone is highly siliceous and contains quartz grains of the same peculiar character as those in the bed of sandstone itself.

Chemical analyses show that the sandstone contains 96.50 per cent of silica, is free from iron, and is valuable for glass making. Usually it is very friable and so incoherent that it crumbles between the fingers. Its most interesting feature, which may be observed with the aid of a microscope, is the fact that the originally rough, angular, or eroded grains of sand have been enlarged by the deposition of silica upon them, which has given them crystalline faces and edges. This secondary enlargement of the grains, many of which have thus become hexagonal prisms with terminal pyramids, gives to the sand a peculiarly brilliant luster. The peculiarity just referred to is well displayed by samples of the sandstone taken from the Campus well at Ann Arbor.

DEVONIAN SYSTEM.

DUNDEE LIMESTONE.

The Monroe formation is the surface rock over only a few square miles in the southeast corner of the quadrangle in the southern part of Exeter Township, Monroe County. On its northwest border is an area about 5 miles wide extending from northeast to southwest across the quadrangle through Sumpter, northwestern Exeter, and southeastern London townships, in which limestone of the Dundee formation is the surface rock. Numerous farm wells enter it at depths ranging from 50 to 100 feet or more. It is also penetrated by deep wells at Milan, Ypsilanti, and Ann Arbor. Its thickness at the Milan well, as interpreted by Lane, is 125 feet, at Ann Arbor 185 feet, and at Britton, just south of the limits of the quadrangle, 100 feet. Samples from the Britton well are reported to be a white or brownish crinoidal limestone; at other points it is reported to be of white or gray color with occasional brownish layers. The water it carries is generally charged more or less with hydrogen sulphide.

TRAVERSE FORMATION.

The traverse formation includes blue argillaceous limestones and shales with reefs of limestone (some dolomite), of about the same age as the Hamilton and Marcellus formations, of the New York series. It forms the surface rock in a narrow area running from northeast to southwest through southern Van Buren, northwestern Sumpter, southeastern Augusta, southeastern York, northwestern London, central and southeastern Milan, and southeastern Macon townships. It has been reached by numerous farm wells in Augusta, London, and Milan townships, at depths of 50 to 100 feet or more, and is penetrated by deep wells at Ypsilanti, Ann Arbor, Milan, and Britton. Its thickness is 65 feet at Ann Arbor and 190 feet at Britton, at each of which points it is completely covered by later rock formations. At Milan, where its upper part has probably been partly removed, since it forms the surface rock, its thickness appears to be only 140 feet. At this point however, the boundary between the Traverse and the Dundee is somewhat uncertain.

ANTRIM SHALE.

The Antrim or black shale forms the surface rock in a narrow strip in Canton, Van Buren, Ypsilanti, Augusta, York, Saline, Milan, and Macon townships, but it is generally covered to a depth of about 100 feet by glacial deposits. It has been reached by a few farm wells in the townships named, and has been penetrated by deep wells at Ypsilanti, Ann Arbor, and Britton.

It is not present in the Milan deep well but is reached by private wells in the northern part of the village. Its thickness at Ann Arbor is 160 feet in the campus well as interpreted by Lane, and it appears to have a thickness of 175 feet at the court-house well as interpreted by Rominger. At Britton its thickness is 117 feet, but there it has probably been partly removed.

CARBONIFEROUS SYSTEM.

BEREA SANDSTONE.

This formation is not easily separable in well sections from the next younger formation, the Coldwater, which, though largely shale, contains lenses of sandstone very similar to the Berea. It can only be stated that the Berea sandstone underlies a narrow area immediately northwest of the black Antrim shale. The thickness of the entire formation in the campus well at Ann Arbor, as interpreted by Lane, is 120 feet, but of this only 15 feet is described as sandstone. In the court-house well at Ann Arbor Rominger found 92 feet of Berea sandstone.

COLDWATER SHALE.

The Coldwater shale, as indicated in fig. 1, is the surface rock beneath a large part of the quadrangle. It consists mainly of shale, but the shale is in places sandy and the formation comprises lenses of sandstone of considerable extent. It is reached by only a few deep wells, since the drift covering it in this quadrangle is very thick. The section of the campus well at Ann Arbor is shown in fig. 4 and sections of other wells that penetrate the formation at Ypsilanti and Ann Arbor are given below.

At Ypsilanti three deep wells have been drilled for the purpose of obtaining mineral water. A fourth well has been drilled with the hope that oil or gas will be discovered in paying quantities. The first of these wells, known as the Cornwell, was drilled on the flood plain east of Huron River, near the present pumping station of the city waterworks, where the surface stands about 680 feet above sea level. The section passed through is reported to be as follows:

Section of Cornwell well, Ypsilanti.

	Thickness in feet.	Total depth in feet.
Earth, clay, gravel, sand, etc., unconsolidated	109	109
"Slate" (probably shale)	241	350
"Flint"	5	355
Sandstone	38	393
Soft "slate" or sandstone (sandy shale)	157	550
"Bed rock" (hard limestone?)	200	750

Mineral water was obtained, but the well is not now in use.

The Moorman well, located near Huron street, in the business portion of the city, at an elevation of about 703 feet above tide, is 950 feet deep. No reliable record of the strata passed through is known. The mineral water obtained (see analysis under heading "Water resources," on p. 14) is used for baths and other purposes.

The Owen or "Atlantis" well, located near the Michigan State Normal College (surface elevation about 760 feet above sea level), passed through the following beds:

Section of Atlantis well, Ypsilanti.

[From manuscript notes by Alexander Winchell.]

	Thickness in feet.	Total depth in feet.
Sand, clay, gravel, etc., unconsolidated	185	185
Shale, soft	4	189
Sandstone, fine, slightly calcareous	10	199
Limestone, fine; all dissolves in acid	10	209
Shale, dun, dark; lower 74 feet black	84	293
Shale, sandy, dun	64	357
Sandstone, very fine, slightly calcareous; yields bromine water	4	361
Limestone, pale, cherty	10	371
Shale, sandy	5	376
Limestone, ranging from pale and cherty to dun and sparry	43	419
Shale, bluish to dun, in places gritty	22	441
Limestone, varying from siliceous to pure	24	465
Shale	21	486
Limestone, varying from pale to dun, with some shaly partings, portions magnesian, others siliceous; contains sulphurous (H_2S) water	138	624
Unrecorded	184	808

At Ann Arbor two deep wells have been drilled, the first in 1871, in the court-house square (surface elevation 835 feet), and the second during 1899 and 1900, in the campus of the University of Michigan (surface elevation 880 feet). The record of the campus well as determined by State Geologist Lane, is given in fig. 4. The section passed through by the court-house well, condensed from

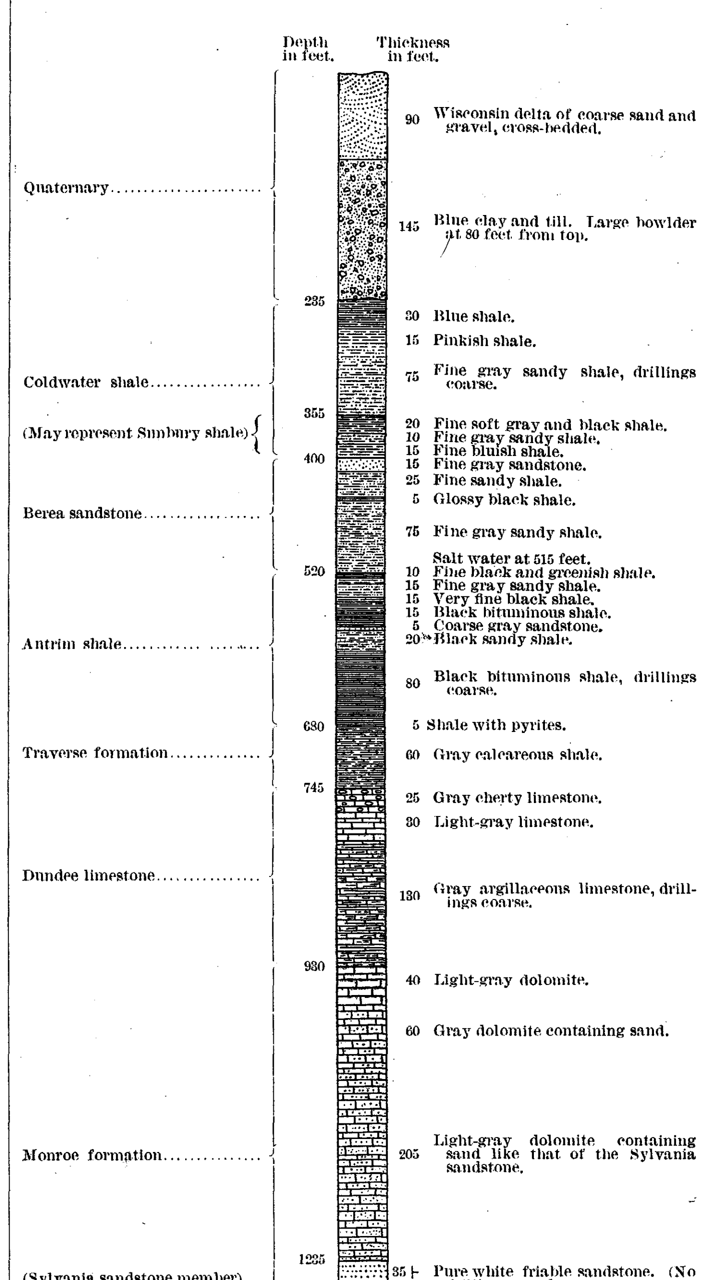

FIG. 4.—Section of University campus well at Ann Arbor.

the report published in vol. 5 of the Michigan Geological Survey, is as follows:

Section of court-house well, Ann Arbor.

	Thickness in feet.	Total depth in feet.
Soil, gravel, clay, etc., (glacial deposits) (According to Winchell thickness of drift is 164 feet.)	155	155
Shale, blue, arenaceous, with seams of fine-grained sandstone	150	305
Shale, black, bituminous, with gas and drops of oil	28	333
Sandstone, gray, with brine	92	425
Shale, blue, with sandstone layers, and seams of pyrite	100	525
Shale, black, very bituminous, with pyrite	85	610
Shale, dark blue, arenaceous, with pyrite, traces of fossils	22	632
Shale, black, bituminous, with pyrite	68	700
Limestone, bluish, cherty	70	770

In sec. 23, Bridgewater Township, a well was drilled for oil to a depth, as reported, of about 1000 feet, but a record of the material passed through has not been obtained.

A deep well was also drilled for oil and gas at South Lyon, of which no record has been obtained.

MARSHALL SANDSTONE.

The Marshall sandstone is present in the western part of the quadrangle from Freedom Township northward to the northern border. Its eastern edge is very irregular and the quadrangle seems to include only its projecting points, for the Coldwater shale forms the surface rock at some places in the northwestern townships as far west as the limits of the quadrangle. As indicated in the discussion of the bed-rock surface this sandstone seems to form an escarpment that stands 100 to 200 feet above the bordering areas, in which the Coldwater formation is the surface rock. The distance to the sandstone at places near the western edge of the quadrangle is only 50 to 100 feet, or scarcely one-third the general distance to the Coldwater shale in that region.

The formation, as reached by borings on the western edge of the quadrangle, consists of alternations of soft sandstone and shaly material. In its outcrops farther southwest, in Jackson and Hillsdale counties, it is a firm sandstone, which has been quarried for use as building stone, and in places for grindstones. The thickness of this sandstone penetrated by wells at Hillsdale appears to reach about 1000 feet, but at Jackson the drillings, as interpreted by the Michigan Geological Survey, show a thickness of only 100 feet. At Albion and Marshall the formation is not far from 200 feet thick. It thus appears to vary greatly in thickness within short distances. The principal exposures outside of Jackson and Hillsdale counties are in Huron County, east of Saginaw Bay, and the rock there varies considerably in texture, ranging from shale to a very coarse sandstone or even a conglomerate and including beds suitable for grindstones.

This formation underlies the coal-bearing strata of Michigan called the "Coal Measures" and extends a few miles beyond their limits, not only in southern Michigan but in the western, central, and eastern portions of the Southern Peninsula. It should be remembered that the so-called "Coal Measures" of Michigan occupy a lower place in the geological column than the strata to which that name has been applied in the Appalachian basin and have received this name simply because they bear coal. In its outcropping or border portions the Marshall sandstone constitutes one of the principal sources of drinking water and its supply is preferred to the waters of the drift because it is softer. In its deep-lying portions, however, under the "Coal Measures," this formation is filled with brines.

SURFICIAL GEOLOGY.

PLEISTOCENE DEPOSITS.

GENERAL GLACIAL FEATURES.

Complexity of the glacial drift.—The glacial drift of North America is separable into deposits or formations of somewhat different age and origin, one formation being superimposed on the weathered and eroded surface of another, or separated from it by a bed of peat or a well-defined soil. The degree of weathering displayed by some of the buried land surfaces is greater than the weathering found on the surface of the uppermost sheet of drift; from which it is inferred that the time involved in the interglacial weathering was longer than the time since the latest drift sheet was laid down.

Centers of ice accumulation.—There were several centers of ice accumulation, from which the ice spread in all directions. One of these centers, from which radiated what is known as the Keewatin ice sheet, was in central Canada, west of Hudson Bay; another ice mass, the Labrador, was centered on the Labrador Peninsula; a third lay west of the Rocky Mountains in Canada; while Greenland is still largely covered by a fourth great ice sheet. It is only with the first and second ice sheets that the drift of Michigan has any relation. From the Keewatin center the ice extended as far south as northeastern Kansas and central Missouri. It may possibly also have spread southeastward over Michigan to Indiana and Ohio, though in that case it must have withdrawn in an early part of the glacial epoch, prior to the great invasion from Labrador. From the Labrador center the ice at its maximum extended as far southwest as southeastern Iowa and southern Illinois and as far south as northern Kentucky.

The principal divisions of the drift in the North Central States are given in the following table, which includes also the intervening soils and weathered zones. The latest drift sheet is named at the top in this table and earlier deposits are set down in order of age beneath. Their names are taken from States or regions in which they are well displayed. The drift sheets east of the Alleghenies, except those formed by the latest or Wisconsin drift, have not yet been correlated to the satisfaction of all geologists with those of the North Central States, and there is similar uncertainty as to the correlation of the eastern drift with drift sheets in the Cordilleran region. For this reason the table given below is restricted to the country lying between the Rocky Mountains and the Alleghenies.

Drift sheets of the Keewatin and the western part of the Labrador ice fields.

Keewatin.	Labrador, west of Allegheny Mountains.
Wisconsin drift.	Wisconsin drift.
Peorian soil.	Peorian soil.
Iowan drift (?) and main loess deposition. (The presence of an "Iowan" drift is not established.)	Iowan drift (?) and main loess deposition.
Not differentiated from Yarmouth.	Sangamon soil.
No Illinoian drift discovered.	Illinoian drift.
Yarmouth soil	Yarmouth soil.
Kansan drift.	Old drift in Pennsylvania, not differentiated; perhaps wholly pre-Kansan.
Aftonian soil.	
Pre-Kansan drift.	

Lobation of ice.—At certain places and at different times the ice margin was divided into prominent lobes and the moraines were arranged in great loops encircling the southern ends of the large basins. (See fig. 5.) The cause of the lobation is found in the fact that the ice mass was necessarily thicker in the basins than on the bordering highlands so that there was more vigorous movement in the thicker ice and a corresponding extension of lobes of ice into the basins. Such lobation was probably strong when the ice came into the basins in the oncoming of the glaciation and again when it was in the waning stage. In the waning stage it left moraines that show the amount of lobation.

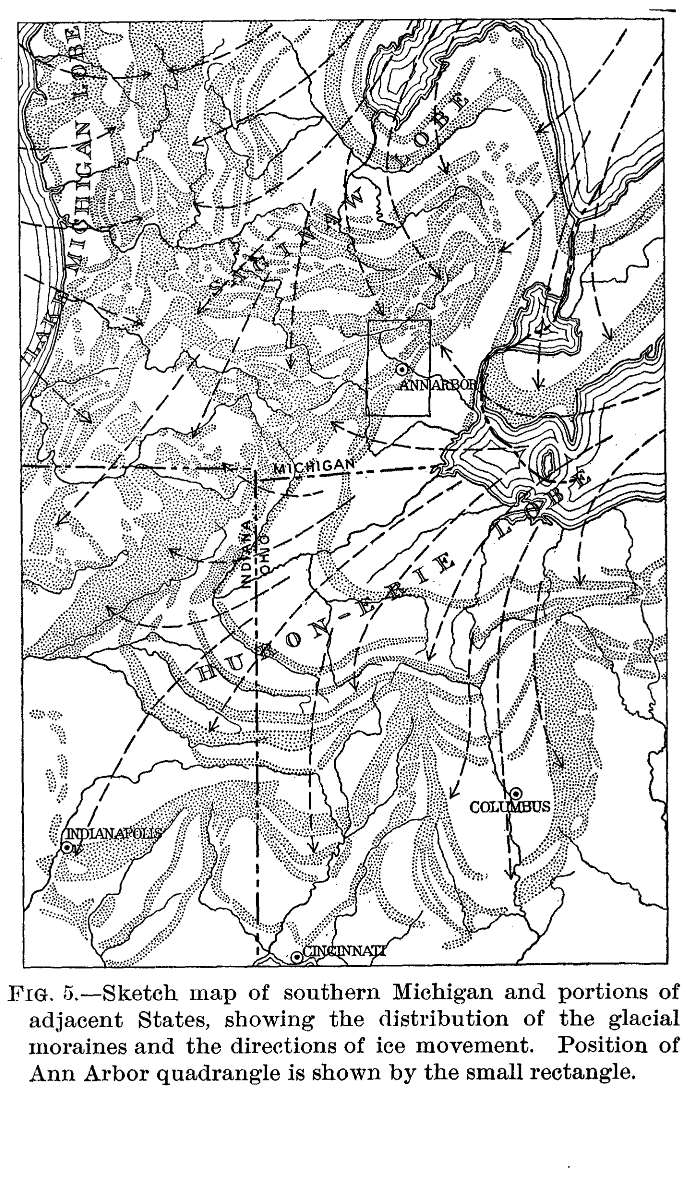

FIG. 5.—Sketch map of southern Michigan and portions of adjacent States, showing the distribution of the glacial moraines and the directions of ice movement. Position of Ann Arbor quadrangle is shown by the small rectangle.

What is true of one glacial advance and retreat is probably true of all that have occurred in the Great Lakes region. At certain times in two or more of the great stages of glaciation the Southern Peninsula of Michigan was occupied by three large lobes, the Michigan, the Saginaw, and the Huron-Erie, each of which formed prominent morainic systems concentric with the border of its basin. The lobes that touched the Ann Arbor quadrangle are the Saginaw and the Huron-Erie. (See fig. 5.) The Saginaw lobe came into it from the north, reaching, at its greatest extension, about to the borders of the southwest-flowing portion of Huron River, while the Huron-Erie lobe entered from the east and covered the greater part of the quadrangle.

Moraines.—Ridges of stony drift formed at the margin of the glacial lobes are very conspicuous features in Michigan. These morainal ridges range in width from a mile or less up to several miles, and in height from about 25 feet up to nearly 500 feet. The surface of the morainal areas of the State is ordinarily very uneven, made up of knolls and interlocking ridges among which basins are inclosed, but the moraines also exhibit all shades of topography ranging from this sharp expression down to a nearly featureless smooth ridge. Most of the smooth ridges occur where the ice lobe terminated in a body of water and are known as water-laid moraines. The Wisconsin drift carries a complex series of moraines, most of which mark stages of halting, though some represent slight readvances during the general recession and disappearance of the ice. In places these are superimposed upon or pass across morainic ridges that were formed in earlier stages of glaciation. These moraines and their included lakes give the Southern Peninsula of Michigan much of its picturesque scenery.

Kames.—In Michigan the drift has been more largely modified by water than in the neighboring States of Ohio, Indiana, and Illinois. In some places it is completely assorted and lies in level-topped deposits. In other places it is imperfectly assorted, and masses of bowlder clay or commingled drift are more or less intricately associated with assorted beds. Combinations of commingled and assorted drift that take the form of sharp knolls and ridges are known as kames. Some of these in the Ann Arbor quadrangle constitute its most prominent features, as will be seen by reference to the geologic map. Many of the kames are in the midst of morainic belts; others are on the plains between moraines. Some of them were probably formed at points where streams emerged from beneath the ice; others may have originated in connection with moulins or glacial mills, at some distance within the limits of the ice sheet.

Eskers.—Long, narrow gravel ridges, most of which lead from a till plain into a moraine and are thought to be the product of drainage within or beneath the ice, are called eskers. One conspicuous example of this class of deposits in the Ann Arbor quadrangle is known as the Lima esker, which is described below in connection with the interlobate moraine of the Saginaw and Huron-Erie lobes.

Glacial outwash.—In the Ann Arbor quadrangle, as well as in other parts of Michigan, there are extensive deposits of gravel and sand that head in moraines and lead outward from them. These deposits were formed by streams that flowed away from the ice. Those that fit somewhat closely the edge of the moraine and do not extend far away from it are known as outwash aprons, but those that lead directly away from the moraine in long narrow strips and turn into valleys are known as valley trains and gravel plains.

Some of the beds of assorted material which appear underneath the uppermost till sheet were probably spread as outwash in front of the ice and subsequently overridden by the ice in its next advance. It is not likely, however, that the gravel interbedded with the till sheets was all deposited as glacial outwash, for at some places it contains strips and partitions and lens-shaped masses of till that appear to have been deposited beneath the ice, within or at its margin. The gravel interbedded with the till is very extensive and carries water that is largely drawn upon by wells.

Ground moraine, or till plain.—Most of the comparatively smooth areas lying between the moraines are underlain by a sheet of till, or of till containing more or less extensive inclusions of gravel and sand. This deposit was probably in large part formed beneath the ice rather than at its extreme edge, and has been called ground moraine to distinguish it from the terminal moraine formed at the border of the ice. The preponderance of till in these plains has also led to their being called till plains, to distinguish them from the outwash plains of gravel and sand.

Striæ.—At the quarries about 1 mile northeast of the village of Maybee the surface shows heavy glaciation, including traces of two and perhaps three distinct movements, as well as considerable shifting in each movement. One set of striæ shows a bearing ranging from S. 19° W. to S. 30° W., with heavy grooves bearing S. 22° W. These grooves and the striæ in them are older than certain others that pass over them nearly at a right angle. These later striæ range from N. 18° W. to N. 40° W., with a general bearing about N. 30° W. In a small quarry south of the main or Woolmith quarry striæ were found bearing more nearly westward and presenting a range of 40°, from N. 51° 30′ W. to N. 91° 30′ W. (Sherzer, W. H., Jour. Geol., vol. 10, 1902, p. 213.)

As the ice movement may have shifted within a single stage of glaciation, it can scarcely be assumed that the several sets represent as many stages of glaciation. The ice probably had a general southwestward movement at both the Illinoian and Wisconsin stages at the time of its greatest extension. But as it shrank and as lobation in the basins of the Great Lakes became more prominent, its movement might easily have shifted from southwestward to northwestward. The northwestward-bearing striæ are directed toward the moraines of the Huron-Erie lobe, which traverse the central portion of the Ann Arbor quadrangle and were probably formed at or near the close of the Wisconsin stage of glaciation. Whether the southwestward-bearing striæ belong to the Wisconsin or the Illinoian stage can not yet be decided.

PRE-WISCONSIN DRIFT.

There is some uncertainty as to the number of drift sheets present in the Ann Arbor quadrangle. The Illinoian and Wisconsin sheets are well represented, but the Iowan sheet has not been identified, nor is it known whether the drift comprises an older sheet than the Illinoian. In view of this uncertainty the drift that underlies the Wisconsin is here considered under the above general heading.

The drift sheet supposed to be Illinoian consists mainly of hard or notably compact till underneath the Wisconsin drift. This hard till is traceable southward by means of well records to unquestionable Illinoian drift, which emerges from beneath the Wisconsin in southern Indiana and Ohio. The indurated condition of this lower part of the drift in Michigan is very similar to that of the exposed portion of the Illinoian farther south, and when taken in connection with the known occurrence of a similar sheet through the intervening territory creates a strong presumption that it belongs to that drift sheet. Furthermore, the occurrence of Illinoian drift as far north as Michigan is naturally to be expected, because the Labrador ice field (which deposited the Illinoian drift) passed across this region to regions farther west and south, where that drift is exposed. The only question seems to be whether or not the pre-Wisconsin drift is wholly Illinoian.

The greater compactness or induration of this drift has not yet been fully explained, even for its exposed portions, but is apparently due in large part to a calcareous cement that has had sufficient time to permeate its compact and clayey as well as its looser textured portions and to bind its particles together. It is true that at some places the Wisconsin drift also has been cemented, but so far as observed this cementation occurs only in material that is readily pervious to water. Ordinarily the Wisconsin drift is so soft that it may be excavated easily with a spade, while the Illinoian usually requires a pick, and blasting is at some localities necessary to loosen it sufficiently for handling.

The amount of pre-Wisconsin drift in the Ann Arbor quadrangle is much greater than was at first supposed. This older drift not only fills preglacial valleys and extends over the general region, but appears to form the nucleus of the large morainic ridges within the quadrangle. Indeed, the principal moraine traversing the quadrangle from its northeast to its southwest corner seems to have been formed in pre-Wisconsin time and simply veneered with Wisconsin drift. Valleys of considerable depth had been cut in this older drift before the Wisconsin was deposited, so that along the line of such interglacial valleys the Wisconsin drift extends down to levels about as low as the present stream beds.

No remnants of soil at the junction of the Wisconsin and pre-Wisconsin drift sheets have been observed within the limits of this quadrangle, but at a point only a few miles farther southwest, in central Hillsdale County, there is a tract, comprising several square miles, in which a black soil underlying the Wisconsin drift has been penetrated by wells. At many places in the northern counties of Indiana also soil has been found between the Wisconsin drift and that which underlies it. In view of these occurrences of buried soil in neighboring districts it may be expected that similar soil will be recognized in this quadrangle when deep borings become more numerous or when the records of the present borings are more fully worked up and interpreted. Buried soil may also be discovered in outcrops along the bluffs of streams, though such situations are generally unfavorable for its preservation. Some of the upper part of the overridden drift sheet was removed in prominent places by later glaciation, and remnants of soil may therefore be present only in protected situations.

A deposit of pre-Wisconsin drift within this quadrangle was noted by Alexander Winchell in a record of the court-house well at Ann Arbor, in which at a depth of 131½ feet a change occurred from an adhesive blue clay, apparently the Wisconsin drift, to a "compactly bedded shalelike material," which appears to be an older drift sheet. The record indicated the presence of 28½ feet of shalelike material, which was underlain by 4 feet of partly cemented sand, the bed rock being struck at a depth of 164 feet. The court-house stands on ground that is about 90 feet above Huron River, so that the adhesive blue clay or till at this point extends down to a level about 40 feet below the river, but, as indicated below, probably here fills an interglacial valley.

The Ann Arbor Water Company sunk a well in 1902 about one-half mile west of the court-house, on ground 25 feet lower, in which the change from soft adhesive blue till to the harder till occurred at 102 feet, or at nearly the same level as in the court-house well. Samples of the indurated material taken from this well consist of a very stony hard till for a depth of 15 feet and a more sandy till, with fewer pebbles, 21 feet farther, and beneath this a thin bed of water-bearing gravel resting on the Coldwater shale, which was found at a depth of about 140 feet. In another boring made by the water company in 1904, about one-eighth mile farther west, the hard till was found at 141 to 163 feet, its surface being a few feet lower than in the wells just mentioned. A well sunk by the Ferdon Lumber Company, in the valley of Huron River, one-half mile north of the court-house, entered very hard till at 14 feet and continued in it to bed rock, which was reached at a level 130 feet below the river. In this well the surface of the hard till is 40 feet or more higher than at the court-house and water company wells, and its base is considerably lower than at these wells.

Wells recently sunk around Ann Arbor and in other parts of the quadrangle have struck the sheet of hard till, and its outcrop has been lately observed at a few places in the valley of Huron River. A comparison of the altitudes at which the hard till has been struck in these wells shows that its surface rises toward the west at an inclination corresponding rudely to the rise in the present surface until it reaches the crest of the main moraine of the Huron-Erie lobe in this quadrangle. Farther west it has not yet been definitely recognized. Its altitude at Denton, on the eastern border of the quadrangle, is about 630 feet, at Ypsilanti 675 to 700 feet or more, at Pittsfield about 825 feet, and at the moraine crossed by Huron River just above Ann Arbor it may be present up to 900 feet or more. Records along this moraine indicate that it reaches an altitude of 930 feet about 5 miles southwest of Ann Arbor. Its greatest thickness probably occurs along this high moraine, for the rock surface beneath the moraine is in places less than 700 feet above tide. East of the ridge and 2 miles north of Ypsilanti, on the Bennett estate, a single well shows great thickness of the hard till, reaching it at a depth of 106 feet and penetrating it to bed rock at a depth of 300 feet.

Some of the best exposures of the hard till are in the bed and banks of Huron River below the city of Ypsilanti. Just below the Ypsilanti waterworks station it forms a reef-like shelf along the west bank of the river, and about a mile farther down, in a point that projects sharply into the valley from the north side, it rises to a height of 25 feet above river level. The preservation of this sharp projecting point seems to be due to the great resistance offered by the hard till to the stream.

A good exposure of what may prove to be pre-Wisconsin drift is found above Ann Arbor, at a point where the Whitmore Lake road rises from the valley to the bluff. A till sheet somewhat harder than the overlying Wisconsin drift, mottled blue and brown, probably by irregular oxidation, here reaches an altitude of 900 feet above sea level. Drift struck in cuts along the Ann Arbor Railroad north of Northfield station, at altitudes of 960 to 970 feet, is so indurated that the laborers working on the railroad found great difficulty in excavating it. In general appearance, however, it is fresher than most of the pre-Wisconsin drift.

Wells along the high moraine leading southwest from Ann Arbor have penetrated 100 to 130 feet of soft drift of Wisconsin age and then entered the hard till. For example, a well in sec. 2, Lodi Township, reached the hard till at a depth of 130 feet and was continued in it to a depth of 230 feet without reaching rock. The hard till here has an altitude of about 930 feet above sea level. Another well, in sec. 36, Scio Township, penetrated about 100 feet of soft Wisconsin drift and then entered the hard till at an altitude of about 920 feet above sea level. Between these wells and Ann Arbor, in sec. 5, Pittsfield Township, a boring penetrated 110 feet of soft drift and entered the hard till at an altitude 822 feet above tide.

The data so far collected seem, therefore, to indicate that a very uneven surface, due in part to irregularities of drift aggregation and in part to interglacial erosion, was present at the time of the readvance of the ice in the Wisconsin stage of glaciation; and the Wisconsin drift has simply veneered the surface and only partly concealed its features.

INTERGLACIAL VALLEYS.

If the large moraines are correctly referred to pre-Wisconsin drift, the drainage of pre-Wisconsin time should conform with the distribution of these moraines. Along the Huron valley and its tributaries in the vicinity of Ann Arbor there are features which seem to indicate that the course of interglacial drainage (like one of the courses of Wisconsin glacial drainage noted in the discussion of drainage development) followed the present line of Huron River down to the city of Ann Arbor and there, after making an oxbow bend through the western part of the city, passed southeastward into Pittsfield Township. Its course, however, is not traceable as a surface feature. A tributary of this interglacial Huron Valley from the north probably came through the valley now utilized by the Ann Arbor railroad in its course from Whitmore Lake to Ann Arbor. The floor of this interglacial valley, as indicated by the depth of the Wisconsin drift in the court-house and water company wells, was a little lower than the present level of the river. According to this interpretation the gap in the high land east of Ann Arbor, through which the river now passes, was probably made at the time of the Wisconsin ice invasion.

WISCONSIN GLACIAL STAGE.

THE INTERLOBATE MORAINIC TRACT.

Area and character.—The Ann Arbor quadrangle embraces in its northwest corner a small section of the interlobate moraine and the attendant gravel plains developed between the Huron-Erie and Saginaw ice lobes during the Wisconsin stage of glaciation, when the remainder of the quadrangle was occupied by the Huron-Erie ice lobe. The interlobate tract was the first to emerge from the ice sheet and the quadrangle became gradually uncovered from northwest to southeast with the recession of the Huron-Erie lobe.

The interlobate tract embraces the portion of the quadrangle that lies north of a line leading from Fourmile Lake past Whitmore Lake to the hamlet of Greenoak. This tract, however, was not formed from end to end at one particular time, as were some of the moraines farther southeast, but was built up and extended along the line of retreat of the junction of the two ice lobes, and, as indicated by the geologic map, is very broken. The part north of Fourmile Lake was formed earlier than parts along the westward-flowing stretch of Huron River and is of interest in that it was the portion of the quadrangle that first become free from ice.

The features built up along the line of retreat of the junction of the ice lobes are complicated and their study in detail will probably help to show the mode of development of interlobate moraines. Indeed, the portion of the interlobate tract that falls within the limits of this quadrangle not only well illustrates in its variety of topographic features the character of the great belt of which it forms a part, but serves as a fair sample of the usual diversity of interlobate areas in other places. In northwestern Dexter and southwestern Putnam townships the surface is remarkably rugged, sharp ridges and knolls inclosing deep basins. In eastern Dexter and northwestern Webster townships there are prominent gravelly hills or kames. A high kame stands immediately north of Pinckney and there are others near Winans Lake, northeast of Hamburg, and north of Whitmore Lake. These kames are conspicuous landmarks of the region, for they may be seen at a distance of several miles. Immediately southwest of Hamburg the basins in the moraine are more conspicuous than the ridges and knolls, though the surface among the basins is far from level.

The Saginaw component.—In northwestern Hamburg and northeastern Putnam townships is the portion of the interlobate moraine developed by the Saginaw lobe. Its northwest or iceward border extends beyond the limits of the quadrangle and merges into a till plain. Its southeast border is at the edge of a gravel plain or line of glacial drainage which was formed between the two ice lobes. Aside from the kames the moraine is not prominent. In this area as in the tracts southwest of Hamburg the basins are more noticeable than the hills and ridges. An inconspicuous group of drift knolls 1 mile to 2 miles east of Pinckney, in the Huron River gravel plain, may be referable to the Saginaw lobe, though it stands somewhat apart from the remainder of the Saginaw component. At the time the two ice lobes completely coalesced in the area now covered by Hamburg Township and the eastern part of Putnam and Dexter the Saginaw lobe extended about to Portage River, in Putnam Township.

Huron-Erie component.—The Huron-Erie component embraces the portion of the moraine on the south side of Huron River from the border of the quadrangle at Greenoak to the bend at Portage Lake, and probably includes also the interlobate tract south of Portage River in Dexter Township. It is interrupted by gravel plains which mark the former course of glacial drainage to the gravel plain now traversed by Huron River, and which divided the moraine into isolated, island-like tracts. The extent of these gravel plains as well as those in the midst of the interlobate moraine is shown on the geologic map.

Basins.—In the morainic part of the interlobate tract, as well as in the gravel plains, there are numerous basins, some of which are occupied by lakes. Other similar basins stand somewhat back from Huron River, along tributary lines of glacial drainage that led into the main line from the north, passing along the later border of the Saginaw lobe, and from the south, through gaps in the morainic ridges along the border of the Huron-Erie lobe. The basins, however, become inconspicuous beyond the limits of the interlobate moraine either north or south of the Huron Valley.

The presence of so many basins in an interlobate tract is generally supposed to be due to the burial in the drift, in the course of its deposition, of masses of ice which, on melting, left the surface indented by basins. The deposition is thought to have been rapid, for the lobes of ice were converging and were concentrating the material. The amount of drift deposited at this time is indicated by the difference between the altitude of the bottoms of the basins and the surface of the bordering gravel plains, or possibly may be measured by the height of the ridges and knolls above these basins. Some of the basins along the border of Huron River reach a depth of nearly 150 feet below the adjacent gravel plains, their bottoms standing 750 feet above sea level. The highest knobs in this interlobate belt exceed 1050 feet in height, thus rising more than 300 feet above the bottoms of the deepest basins.

The depth and extent of the basins in this interlobate belt, together with the fact that they remained unfilled while the ice was retreating to a distance of several miles and discharging a large amount of outwash into this westward-flowing part of the Huron, seems to indicate that the outlying ice blocks persisted in the drift for a period to be measured in centuries if not in thousands of years. With a view to determining the probable or possible length of time that such masses of ice might persist in the deeper basins, an estimate has been made by Lane, from which it appears that masses 100 feet thick, buried to a depth of only 2 meters by a cover of gravel having a temperature of 2° C. would persist about 450 years, while if the temperature were but 1° C., which is not unlikely, the time required for melting would be doubled. Should the cover have been thicker than 2 meters, as seems probable in some places, the ice would have been preserved longer. The estimate therefore indicates that the larger masses of ice may have persisted more than a thousand years. In this connection attention is directed to the fact that small masses of ice derived from Alaskan glaciers have been preserved in a lateral moraine for a time during which the glacier has shrunk to a level 300 feet lower and to a distance a mile farther up its valley than it occupied at the time these masses became detached from the glacier. (G. K. Gilbert, Glaciers: Harriman Alaska Expedition, vol. 3, p. 56.)

A moderate settling of material appears also to have occurred in portions of bordering gravel plains. For example, the general level of the gravel plain near Portage Lake and Pinckney is about 900 feet, while the level at the divide, 10 to 15 miles farther west, is fully 20 feet higher. Yet the glacial waters were discharged westward, across the divide. The character of the bedding in the deposits near Portage Lake indicates a vigorous current of water, the material being largely gravel. It can not therefore be assumed that the low area was occupied by a pool, and it seems necessary to infer that the amount of settling here has been greater than at the divide. It may be supposed that a thin sheet of ice was buried here, which, on melting, let the material down, as in the basins. But the settling may have been brought about in other ways. The greater amount of settling may be due in part to the greater thickness of loose material deposited in this lower region, east of the divide, for it was here apparently fully twice as thick as on the divide. The water apparently percolated more rapidly through this lower portion, bordering Huron River, than through that on the divide, and the resulting greater solution of limestone and other soluble material would also lead to settling.

Closely connected with the southern part of the interlobate moraine is an esker which will be considered before the inner border district is described.

The Lima esker.—The Lima esker is the only representative of this class of glacial ridges noted in the Ann Arbor quadrangle. In its length of nearly 5 miles it lies entirely within the limits of Lima Township, its head being in the eastern and its terminus in the northwestern part of the township. It connects through a chain of kames west of Fourmile Lake with a large kame mass on the inner border of the interlobate moraine northwest of the lake. It lies along the borders of a swampy depression that is traversed by the outlet of Fourmile Lake, though the stream that formed the esker, as shown by its bedding, flowed in a direction the reverse of that taken by the lake outlet. The esker stretches westward from Mill Creek valley to Lima, but its trend there changes abruptly from west to about north-northwest, a course which it maintains to its terminus. Along its course it exhibits also minor curvings and meanders. From Lima northward it is a nearly continuous ridge, but east of that hamlet it is interrupted by notable gaps. A short eastern tributary, less than one-half mile in length, joins the main esker about one-third mile north of Lima.

In height the Lima esker ranges from 5 feet or less to about 20 feet, and in breadth from 50 feet to about 500 feet. Its slopes are generally rather gradual, for it is steep sided at only a few points. The topographic sheet shows that it has a range in altitude of nearly 60 feet, but this is due to its position—that is to the altitude of its base—rather than to variations in its own height. Where it stands in the bottom of the marshy depression its altitude is not far from 880 feet, but on the edge of the bordering till tracts it reaches 940 feet, while in its usual position on the slope it stands between 900 and 920 feet above sea level.

The esker is composed of a rather sandy gravel in which the pebbles are not conspicuously rounded or waterworn. Among the pebbles are fragile pieces of black Devonian shale, which seem to have been subjected to remarkably little stream battering. From these features it is inferred that the material of the esker was very little transported, but was deposited very soon after its release from the ice. Very few of the pebbles exposed on the surface and in the gravel pits were brought from distant sources. Most of them were derived from rocks that outcrop in southeastern Michigan between the esker and the western end of Lake Erie, and apparently less than one-tenth of the coarse material is from Canadian crystalline rocks. It is of interest to note that much of the material in the esker stands 300 to 350 feet higher than the ledges from which it was derived. This lifting of the material was probably accomplished by the ice, and not by the esker stream, for the ice sheet passed from the lower into the higher country.

The Lima esker and its attendant features may throw some light on the question of the horizon of esker development in the ice sheet, though the conditions that prevailed at the time the esker was formed are not yet fully understood. The occurrence of so large a percentage of local material seems best explained on the hypothesis that the esker stream traversed the basal portion of the ice sheet, for this material is unlikely to have risen to a great distance into the ice. The occasional gaps in the esker and its lack of strict conformity to the line of lowest altitude in the depressed tract which it follows appear to indicate that the esker stream was, in places at least, floored by ice, and was therefore slightly above the ground surface beneath the ice sheet. Another feature suggesting that the horizon may not have been so low as the bottom of the ice sheet is the accumulation of gravelly material in kames at the terminus of the esker up to an altitude notably higher than the surface of the ground moraine along its course—at places higher even than its crest. The kame southwest of Fourmile Lake reaches an altitude of more than 960 feet, and the group northwest of the lake has points that stand more than 1000 feet above tide, or nearly 100 feet above the general level of the esker. The heaping of this gravel at the terminus of the esker seems to point either to the esker-forming stream as a contributor, or to an earlier stream or streams, following essentially the same course. The uncertainty as to the altitude of the contributing stream or streams is increased by the presumption that the water may have gushed up at the margin of the ice. A stream might thus reach a higher altitude in building the kames at the margin than it had when building the esker beneath or within the ice sheet. Observations made by Russell at the border of the Malaspina Glacier show the presence there of strong gushing streams such as are here suggested. While, therefore, the esker stream may have been floored by ice, it is not certain that its horizon was so far above the level of the base of the ice sheet as to give a continuous descent to the kames that were apparently formed by it at the ice margin.

The low tract which the esker follows is a characteristic feature of this and many other eskers. It is a strip one-fourth to one-half mile wide, which stands 20 to 40 feet lower than the bordering land. That it was not formed by postglacial erosion is made certain not only by the presence of the esker on its bed and slope, but by its general freedom from erosion features. The inequalities of its surface are such as result from glacial deposition rather than from stream erosion. It seems to mark a belt in which the ice sheet supplied insufficient material to build up the surface to the general level, while the mass of kames at the northwest end of the tract suggests the place to which the glacial material was carried and deposited. This lack of material, it is thought, may have resulted from the fact that streams (such as that which formed the esker) carried much of the material within the ice sheet out to its margin and there built up the kames. Whether or not such a stream would form an esker probably depends on the adjustment of the stream to the size of its channel or tunnel. If the tunnel were large and only partly occupied by the stream an esker might be formed, but if the pressure of the ice kept the tunnel constricted and the head of water in the stream was great, as it would be after vigorous rains or exceptionally warm weather, the current may have been sufficiently strong to carry all the material through the tunnel and build it into kames at the ice margin. The streams carrying this material to the margin would deplete the portion of the ice sheet traversed by them of such material as was within their reach, so that on the complete melting of the ice the depleted portions would be marked by belts of land standing lower than bordering portions that were not thus depleted. The esker-building stage apparently followed the stage in which the material in the tunnels was more completely swept to the ice margin. Indeed, the position of the esker on the surface of the ground moraine seems to indicate that it was formed as the ice was disappearing after all ice movement had virtually ceased, when conditions were favorable for the enlargement of the tunnel in which it was deposited.

RECESSION OF THE ICE FROM THE INTERLOBATE MORAINE.

In melting back from the interlobate moraine the Saginaw lobe withdrew northward and disappeared from the Ann Arbor quadrangle, leaving all of it except its northwestern part in possession of the Huron-Erie lobe.

The interpretation of the first steps in the shrinking of the Huron-Erie lobe within this quadrangle is not easy, it being questionable whether the shrinking went on at a somewhat regular rate all along the border, or whether the ice held its position at certain parts of the border while shrinking in other parts. The withdrawal of the ice from the interlobate moraine in the western part of the quadrangle may have preceded its withdrawal in the northern part, just as the development of the interlobate moraine appears to have begun earlier in the western part.

The western part of the district between the interlobate moraine and the large morainic system farther southeast is generally free from well-defined ice-border phenomena, but a bowldery strip extending along the north side of the swamp in Freedom Township past the southeast end of the Lima esker to Dexter may show the trend of the ice border at a brief halt in its retreat. This bowldery belt is associated with some large kames in southern Lima Township, but elsewhere it is no more undulating or moraine-like than the border districts. This bowldery strip runs nearly parallel with the moraines on each side of it and its position apparently supports the view that the ice border made a general regular retreat.

The northern part of this intermorainic strip, from Dexter northeastward, is much more varied in expression than its western part. For several miles east of the bend of Huron River, in Webster and northern Scio townships, the surface is of morainic type but comprises numerous kames. This area nearly connects at the northwest with the interlobate moraine and thus suggests a somewhat close relation to it, comparable to that of the Lima esker to the moraine. East of Webster Township, in Northfield and southern Greenoak townships, much of the surface is flat and the drift is of a compact, clayey nature except where it is interrupted by strips of the gravel plain that stretch from the southeast to the great gravel plain in the valley of Huron River. The first indication or suggestion of a definite ice border to the southeast of the interlobate moraine is found in a bowldery strip, accompanied by low hummocks and shallow basins, which runs eastward through the central part of Northfield Township and connects in western Salem Township with a moraine of greater strength. At the west it connects with the rolling tract of Webster Township just noted. Few of the knolls in this strip are more than 10 feet high, but these knolls and the basins that accompany them give the surface a wavy appearance, which is in striking contrast to the very flat surface of the gravel plains and is also more varied than that of the till plains of the northern part of Northfield Township. The gravel plains heading in this bowldery strip give added plausibility to the opinion that it marks an ice border.

One of these gravel plains heads in secs. 28 and 29, Northfield Township, and takes a course slightly west of north past Horseshoe Lake to Whitmore Lake, forming a strip a little more than a mile wide. Its surface is indented by shallow basins, one of which is occupied by Horseshoe Lake. The waters that formed this gravel plain seem to have been unable to carry gravel or sand beyond Whitmore Lake, but may have found escape either northeastward, along a sandy strip extending to the south branch of Huron River, or northwestward to Huron River along the line of the outlet of Horseshoe Lake. A series of knolls and marshy depressions south of Horseshoe Lake have the appearance of ice-border phenomena and suggest that this gravel plain was started when the ice stood as far north as Horseshoe Lake and was extended southeastward with the withdrawal of the ice border in that direction.

Another gravel plain heads in the north part of secs. 13 and 14 and covers much of secs. 11, 12, 1, and 2 of Northfield Township. This plain also may have been extended southward with the withdrawal of the ice across northern Northfield Township. The outwash material is coarse, and in a region so nearly level was probably not transported very far from the immediate border of the ice. Thus the extent of a gravel plain may by no means indicate the vigor of the outwash.

Another gravel plain, which is well developed in northwestern Salem and southwestern Lyon townships, extends southward beyond the bowldery belt noted above and connects with a later moraine, but the northern end of it may have been formed before the ice retreated from this bowldery area.

In line with the suggestion just made—that in some places along lines of glacial drainage considerable deposition occurred as the ice was melting back from the interlobate moraine toward its next prolonged halting place (at the outer moraine of the Huron-Erie system)—it may be observed that the coarser deposits are perhaps due in larger degree to strong currents forced out at the ice border or from under the ice by great water pressure within the ice. An inspection of the gravel seems to sustain this view, for much of it is not so well rounded as it should be if transported for several miles down the drainage lines. Other items of evidence also support the view that considerable deposition of gravel attended the retreat of the ice sheet. For example, a gravel strip that heads in northwestern Lodi Township is built up to a level slightly higher than portions of the bordering till plain. This upbuilding could hardly have occurred unless the ice still occupied this till plain while the gravel was being deposited. A gravel strip that heads in central Scio Township and leads westward is loaded with surface bowlders for a mile or more west of its head, as if the deposition had taken place while the ice still covered it, before it had shrunk to the position marked by the head of the gravel plain. Of course the ice border may have oscillated a little and at times extended slightly beyond a moraine while forming it.

MORAINIC SYSTEM OF THE HURON-ERIE ICE LOBE.

Moraines of the system.—The morainic system of the Huron-Erie ice-lobe occupies a belt from 6 to 10 miles wide extending from the northeast to the southwest corner of the quadrangle, as shown on the areal geology map. (See also fig. 5, p. 4.) It includes two and in places three moraines. The outermost or western one is a probable continuation of the Fort Wayne moraine of the Maumee lobe of western Ohio and northeastern Indiana, while the eastern one is a continuation of the Defiance moraine. The middle moraine is weaker and less continuous than the others. From the southern part of the quadrangle southward into Ohio it is merged with the Defiance moraine.

Fort Wayne moraine.—The outer or Fort Wayne moraine is by far the strongest of the system, though, as indicated above, it seems to have a pre-Wisconsin basement ridge. Throughout much of its course across the quadrangle it constitutes a divide between drainage systems. In the area southwest of Ann Arbor it separates the drainage of Huron from that of Raisin River, while in the northeastern part of the quadrangle it separates the drainage of Huron from that of Rouge River. Huron River, it will be observed, passes through the moraine just above Ann Arbor. In this morainic system basins do not form so conspicuous a feature as in the interlobate moraine, a large part of this moraine being characterized by the swell-and-sag rather than the knob-and-basin type of topography. Basins are, however, not rare and a few of them contain lakes. The sharpest hills or knolls of gravelly constitution are generally kames. Besides the prominent group of kames near Pleasant Lake, which carries the highest point in the quadrangle (1107 feet) there is a prominent kame about 2 miles west of Ann Arbor, which rises above the 1080-foot contour. Other kames lie north and east of Ann Arbor, on the north side of Huron River, and a conspicuous group occurs east of Emery.

Middle moraine and associated till plains.—From Ann Arbor northeastward nearly to Salem the middle moraine is scarcely separable from the outer or Fort Wayne moraine, but from Salem eastward to and beyond the edge of the quadrangle is distinct from it. In the region south of Ann Arbor it is distinct from both the others as far as Saline, but is combined with the Defiance moraine in the area between Saline and Tecumseh. Immediately east of Ann Arbor there is a prominent drift mass on which the middle moraine lies; but the material of the moraine here forms only a thin veneer, the main body of drift being in all probability referable to an older or overridden moraine of pre-Wisconsin age. About a mile south of the boundary line between Ann Arbor and Pittsfield townships this middle moraine leaves the high tract and becomes relatively inconspicuous and before reaching Saline River it takes on a complex form, being composed of three parallel, very faint ridges. On the south side of Saline River there is a rather prominent moraine, formed by the combination of this moraine with the Defiance moraine.

The topography of this middle moraine is of the knob-and-basin type near the northeast corner of the quadrangle, but elsewhere is predominantly of the swell-and-sag type, and most of its prominent knolls are kames.

In Pittsfield Township a till plain having an area of 12 to 15 square miles lies between the middle moraine and the Defiance moraine. This is the largest till plain in this morainic system within the Ann Arbor quadrangle. The next in size, covering an area of 2 to 3 square miles, lies immediately north of Salem, between the middle and outer members of the system.

Defiance moraine.—The Defiance moraine enters the quadrangle about 5 miles south of its northeast corner and leads southwestward along the east side of Fleming Creek to the Huron Valley just below Geddes. From that point it takes a curving course southward and westward to Saline River below the village of Saline, and thence to Tecumseh it follows the eastern edge of the combined belt. At some places its eastern slope extends down below the shore of the glacial Lake Maumee. Many irregularities of surface in the lake bed are due to morainic features which have been toned down but not effaced by the action of the lake waves. The portion of the moraine that stands above the level of this old lake exhibits swell-and-sag topography, containing but few basins and lakes.

No definite morainic ridge younger than the Defiance moraine appears within this quadrangle. At the east border of the sandy tract in the southeast corner of the quadrangle, however, a somewhat bowldery strip that runs nearly parallel with the Defiance moraine probably marks the outline of the ice lobe at a brief halt in its retreat. This strip may therefore indicate an iceward limit of Lake Maumee. The abrupt border of the sand at this line is also consistent with this view, for the ice would have prevented the transportation of this material eastward. The streams that were afterward developed in the plain where the ice had stood have carried the sand down their valleys and thus broken at some places the continuity of this line, which otherwise appears to mark an ice border.

LOCAL GLACIAL DRAINAGE.

From the outer or northwestern moraine of this system there were several lines of discharge within the limits of this quadrangle, as indicated on the geologic map. All of these drainage lines converge toward an outlet, westward past Pinckney, discussed under the heading "Drainage development." Two of them, in Novi and Salem townships, were also lines of discharge from the middle moraine, but the others, except that coincident with Huron River, became inoperative when the ice shrank away from the outer moraine. The heads of most of these lines of glacial drainage, as the contour lines show, stand at altitudes between 920 and 940 feet, or but little above the level of the outlet channel near Pinckney. Higher tracts of outwash occur in Freedom Township east of Pleasant Lake; in sec. 25 of Scio Township, south of Sister Lakes; and near Emery, in the southeastern part of Northfield Township. The surface of some portions of the outwash near Huron River in the western part of the quadrangle stand below the 900-foot contour, or lower than the portions at the outlet. It seems probable, as has already been suggested, that, since the deposition of the gravel, these low portions have settled more than those at the outlet, and that the original gradient of the outwash tract has thus been altered. In some places, however, there appear to have been pools in these lines of drainage. It seems hardly probable, for instance, that the lines that head in northwestern Lodi and in eastern Scio townships had well-graded beds from their junction in western Scio Township northward past Dexter to Portage Lake. The grade of the gravel floor of the northern part of the drainage line seems referable to the action of later streams which flowed southward instead of northward, though it may have been begun by streams flowing westward through the outlet at Pinckney.

The line of glacial drainage that heads 2 miles north of Ann Arbor leads northwestward through a well-defined valley standing 20 to 40 feet below the border districts and having a width of about one-half mile until it approaches the northwest corner of Ann Arbor Township, where it becomes much narrower. It continues narrow for a few miles and then opens into a gravel plain nearly a mile broad, standing about at the level of a till plain east of it. The eroded part of the valley, it may be said, terminates at this point. This valley appears to be due to ordinary erosion, and not to be a partly masked interglacial valley. This being the case, its erosion and subsequent filling may be used to estimate the time taken by the ice to form the moraine in which the gravel bed heads.

The glacial drainage from the middle moraine is more difficult to interpret, for when it was formed the ice border stood on the slope east of the outer member of the morainic system, at a level slightly lower than its top. The drainage from the northeastern part of the quadrangle, however, appears to have crossed this moraine and led northwestward along two lines toward the outlet at Pinckney, and may have passed through that outlet. One line headed about 2 miles southwest of Salem, the other 3 miles northeast of the same village, and they came together near South Lyon. Whether the drainage continued northwestward through the Pinckney outlet may have depended on conditions for discharge farther south, and those have not yet been fully investigated. At this time there was apparently an open channel not only down Huron River to the edge of the ice at Ann Arbor but also from Ann Arbor southwestward along the ice front to the valley of Raisin River near Clinton. The ice border there may have extended across to the west side of Raisin River, but need not have obstructed drainage along the outer border of the moraine, for the moraine itself stands generally below 900 feet and the district immediately outside is scarcely 850 feet.

An outwash apron about 875 feet above tide borders the middle moraine in the eastern part of the city of Ann Arbor. It extends from the south bluff of Huron River southward nearly 2 miles and underlies the university campus. This outwash apron was built apparently into a pool or lake that bordered the ice from the site of Ann Arbor southwestward to Raisin River in Bridgewater Township. The lake may have stood a little below 875 feet and its level was probably determined by the lowest available outlet toward the southwest. This is nearly 50 feet lower than the Pinckney outlet, which served as a line of discharge for the glacial drainage from the outer moraine. Back of the outwash apron just discussed is a depression (fosse), separating it from the moraine. This fosse, which extends only from the university campus northward to Huron River, is a striking topographic feature and contains several basins, one of which is known as "the cat hole." The ice border appears to have held its position in this fosse while the outwash apron outside it was built up to a height of about 40 feet.

In the northwestern part of Ann Arbor there is a somewhat older gravel outwash plain which stands at a higher altitude than the campus plain, its upper level being at about 920 feet. This gravel it is likely was deposited while the ice still occupied the low recess in the western part of the city and the valley of Huron River in the northern part. The bedding shows a westward dip from the very brow of the west bluff of the river, indicating that the discharge was westward, probably through a narrow, winding channel across a low part of the outer or Fort Wayne moraine to Sisters Lake, in sec. 25, Scio Township, whence it may have passed to the Pinckney outlet. The Pinckney outlet was therefore probably abandoned when the ice sheet withdrew from the high tracts in the western part of Ann Arbor and thus permitted the drainage to turn away from the present Huron valley at this city and pass southwestward to the Raisin Valley.

The glacial drainage from the Defiance moraine, and probably also that from the headwater part of the Huron valley, took a southwestward course from Ann Arbor to Raisin River in Bridgewater Township, and thence down the Raisin Valley into Lake Maumee. For a time the ice probably covered the course of the present stream below Tecumseh and held the drainage in the area now occupied by the gravel tract west of the river from Tecumseh to Adrian, but before the moraine was completed the ice seems to have left this part of the valley open and permitted Lake Maumee to extend up about to Tecumseh. The drainage connected with the part of the moraine north of Huron River seems for a time to have passed from the mouth of Fleming Creek westward, or up the present valley of the Huron to Ann Arbor, traversing a gravel-filled valley that turns westward from Fleming Creek one-half mile above its mouth. The ice margin then probably rested against the eastern face of the high tract on the south side of the river east of Ann Arbor. When the ice shrank from away this high tract a low passage was opened along its southeastern border. This, however, seems to have been covered by a pool or slack-water body, for it is not graded up to the level of the valley floor north of the river and contains very little gravel or sand such as would have been deposited along it if it had been traversed by a strong current. Another pool probably stood on the outer face of the moraine northeast of Brookville, in the swampy tract now tributary to Rouge River. Near Northville, which stands just east of the quadrangle, the glacial outwash reached a height of 860 feet and marks the probable level of the pool just mentioned. This would carry the drainage across the present gravelly divide south of Brookville between Rouge River and Fleming Creek. Probably the largest pool in the line of this drainage filled the sag now drained by the headwater branches of Saline River between Pittsfield and River Raisin. This pool was perhaps 16 miles long.

It may have been as early as the time when the Defiance moraine was forming that Huron River graded up its bed in the vicinity of Dexter so high that a break in its banks at the site of that village would have carried it into its present course. At least the abandoned section south of Dexter was apparently not affected by the wave of erosion that passed through the valley when the river dropped at Ann Arbor to the level of Lake Maumee—a drop made soon after the ice shrunk away from the Defiance moraine. This abandoned section appears to correlate well with the abandoned course that leads southwestward from Ann Arbor and probably had a life that was nearly coincident with it.

GLACIAL LAKES.

Lake Maumee.

First or upper beach.—The highest of the series of large glacial lakes that occupied the southeastern part of the Ann Arbor quadrangle discharged past Fort Wayne, Ind., to the Wabash and thence to the Ohio and Mississippi and the Gulf of Mexico, the Fort Wayne outlet being for a time the lowest one available. (See fig. 8, p. 10.) This lake, known as Lake Maumee, began with the withdrawal of the ice sheet from the Fort Wayne moraine and with the eastward retreat of the ice became gradually enlarged from northeastern Indiana and northwestern Ohio toward the basin of Lake Erie and northward into Michigan. For a considerable time during the development of the Defiance moraine the area of this lake was probably nearly constant and was restricted to the lowest part of the tract between the Fort Wayne and Defiance moraines in Indiana, Ohio, and southern Michigan. Its water at this stage scarcely touched the Ann Arbor quadrangle, for the low land west of the Defiance moraine in this quadrangle is nearly all above the highest level of the lake. On the withdrawal of the ice sheet from the Defiance moraine the water of Lake Maumee invaded the part of the quadrangle immediately south and east of the moraine and extended up Huron Valley to Ann Arbor. It also filled to some extent the low tracts bordering the Saline Valley inside the moraine, but the clayey tract in the southeast corner of the quadrangle may have been covered by the ice sheet nearly to the close of this highest lake stage.

The occupation of the southeastern part of the quadrangle by the waters of Lake Maumee is clearly shown by such features as are commonly found on the shores and beds of extinct lakes—beaches, bars, and cut banks, produced by wave action, deltas where streams entered the lake, and sandy sediments on the bed of the lake. From the highest beach and the stream deltas the upper limits of the lake may be easily determined. The beach shows some variation in altitude and possibly a slight northward rise in its course across the quadrangle, as indicated below. It seems probable, however, that the variations are due chiefly to fluctuations in level, such as are now exhibited by the Great Lakes. The altitude of the beach generally falls between 795 and 805 feet above sea level, yet at places it reaches 810 or 812 feet, and at one place within this quadrangle and another in the Wayne quadrangle on the east it stands above the 820-foot contour. So great a variation as is required to reach the 820-foot contour is beyond what one would expect from lake fluctuations and storms, and doubt is therefore felt as to the accuracy of the contouring at those points. The place in the Ann Arbor quadrangle is at the extreme northwest corner of the French Claim, about a mile west of Ypsilanti. The delta of Huron River at Ann Arbor is 812 feet, and this apparently marks a high lake level. The lake at its ordinary level, as indicated by the usual height of the beach, stood between 800 and 805 feet, while at extreme low water it may have stood a little below 800 feet.

The altitude of the beach has been determined at several points farther northeast, where it is crossed by railroad surveys, but it shows no marked rise in passing across northwestern Wayne and southeastern Oakland counties, its general altitude being between 800 and 810 feet. From Clinton River, in western Macomb County, northward about 25 miles to Imlay City the beach rises nearly 40 feet or to about 850 feet above sea level. This northward rise in the beach is supposed to be due, in part at least, to a differential elevation of the region in a north-northeast direction. A small part of the northward rise is perhaps referable to ice attraction.

This beach varies considerably in strength, the variation being such as is natural on the slope of a moraine in an irregular region. Where the water was deep off shore, and the shore was unbroken or regular for a mile or more, a good beach was usually formed, but where the shore was broken by morainic knolls or where the water was shallow off shore, the beach is at some points so faint or so discontinuous as to be difficult to trace. In places it is made up of two or more closely associated ridges differing very little in altitude, a conspicuous instance being found in the southwestern part of Ypsilanti Township. As a rule, however, there is very little overlapping or duplicating of the ridges. The lake must have stood much longer at this level in the southern portion of its area, outside the Defiance moraine, than in the northern portion, or that represented in the Ann Arbor quadrangle.

Second Maumee beach.—The second beach of Lake Maumee (perhaps the third in age) stands at a general altitude of 780 to 785 feet in the Ann Arbor quadrangle and may readily be traced along or near the 780-foot contour. At all places it appears to maintain a level parallel with and 20 to 25 feet below the first beach. This difference continues northward to the Imlay outlet, where the second beach stands at about 825 feet. Its altitude where crossed by the railroad east of Almont (about 6 miles from the head of the outlet) is 821 feet, while that of the first beach is 840 feet. The second beach appears at an altitude of about 820 feet on several of the Maumee islands in western St. Clair County, near the head of the outlet. The rise from 785 feet to 825 feet is nearly all made between Clinton River and the Imlay outlet, a distance of 25 miles.

The portion of the second Maumee beach within the Ann Arbor quadrangle is better defined and is more continuous and regular than the portion of the first beach. It is, however, no stronger than the best developed parts of the first beach. It is fully as strong in the Ann Arbor quadrangle as at any place in its course farther south, so that the lake which formed it probably stood as long here as in areas farther south.

The Fort Wayne outlet seems to have been operative for a time in connection with this second beach, but the Imlay or northern outlet may later have taken the entire discharge, for it appears to have been deeper.

Third Maumee beach.—A faint beach (perhaps second in age), easily traced in the southern part of the quadrangle but difficult to trace in the part north of Huron River, stands about 20 feet below the second beach, or near the 760-foot contour. Its relations are not yet fully determined. At many places it presents a rather washed-down appearance, as if it had been submerged, and this feature suggests that after this beach was formed the ice may have encroached upon the lake's outlet (which perhaps stood north of the Imlay outlet), and caused its water to rise to a higher level. Possibly this may prove to be older than the second beach. It appears to have been barely high enough to have opened into the Imlay outlet if its north ward rise is as rapid as that of the first and second beaches. This beach has not been traced southward into Ohio and Indiana.

At Plymouth, Mich., a short distance east of the limits of this quadrangle, this third beach is exceptionally strong, apparently because of material brought in by Rouge River. It also exhibits unusual strength on the fan-shaped gravelly area where Huron River opened into Lake Maumee, east of Ypsilanti. Moreover, this gravelly area appears to be, in part at least, a delta of the Huron and it conforms more closely with the third beach than with the higher ones. The full interpretation of this beach must be deferred until its relations are better known.

Lake Arkona.

A series of weak, fragmentary ridges, three in number, apparently come next in age after the Maumee beaches and precede the Belmore beach, though the position of the latter is between them and the third Maumee beach. These beaches represent a glacial lake known as Lake Arkona. Their weakness and fragmentary character is thought by Taylor to be due to a later resubmergence during which the beaches, which were originally strong and continuous, were nearly obliterated. (F. B. Taylor, Proc. Michigan Acad. Sci., vol. 7, 1905.) The lake that formed these beaches occupied not only much of the district covered by Lake Maumee, but extended into the Saginaw basin and discharged directly through the Grand River outlet to Lake Chicago. The portion of its bed between the Saginaw basin and Lake St. Clair was subsequently covered by a readvance of the ice, and the portion of the lake in the Maumee basin was raised to a higher level, forming a body of water known as Lake Whittlesey.

The highest Arkona beach in the Ann Arbor quadrangle stands about 705 feet with a few points as high as 710 feet, the middle about 700 feet, and the lowest about 695 feet. They are slightly higher in the northern part of the quadrangle and also in much of the Saginaw basin. The development of three beaches is supposed by Taylor to be due to reductions in the height of the Grand River outlet, which by erosion was lowered in such way as to lower the level of the lake in two steps of a few feet each.

The beaches are at most places washed down to scarcely perceptible ridges, but the gravel which they contain marks their courses with much clearness, especially on the clayey parts of the lake bottom.

Evidence that the Arkona beaches mark the shores of a lake of long duration is found in the river deltas. The Huron delta covered several square miles in the southeastern part of Ypsilanti and the western part of Van Buren Township. Saline River formed a large delta, which appears in southeastern York and northeastern Milan townships. The delta of Raisin River is even larger than that of Huron River, but lies south of this quadrangle.

Lake Whittlesey (Belmore Beach).

The beach in this region which seems to have attracted the earliest attention of geologists is the Belmore, named from a village in Ohio which stands on the beach, but known also as the Whittlesey beach. Its course in southeastern Michigan was mapped for fully 60 miles by the first Michigan Geological Survey prior to 1840. It is a large gravel ridge standing usually 10 to 15 feet above the plain on its lakeward side and 5 to 15 feet above its landward border. It is built like a dam across valleys which had been cut down to conform with the preceding lower lake level (Lake Arkona), and in such situations its landward relief is about as prominent as the lakeward. The advancing lake, as suggested by Taylor, appears to have carried the beach farther up the slope and given it a prominence not found in lakes that made no such advance. Then, having reached its highest stage and taken its discharge through the Ubly outlet (see fig. 10), the lake seems to have fluctuated less than some of the other glacial lakes. The outlet is broad enough to have prevented heaping up of lake waters in wet seasons and is in places floored by sandstone rock, which would prevent it from being cut down. The lake was therefore probably kept at a very steady level and might in a certain time have produced a stronger beach than a lake in which the fluctuation of level was greater.

If we may determine the duration of a lake by the size of the deltas of the rivers entering it Lake Whittlesey did not endure so long as Lake Arkona or as its successor, Lake Warren. Indeed, the deltas are surprisingly small, not only in the Ann Arbor quadrangle but at many points beyond its limits. On Huron River the delta deposits lie chiefly between the city of Ypsilanti and the Whittlesey beach, there being a filling or grading up of the valley to correspond with the rise of the lake from the Arkona level.

At a few places in the Ann Arbor quadrangle the Whittlesey beach rises to the 740-foot level, but its crest stands generally between 735 and 740 feet. For a distance of 300 miles along the western and southern shores of the lake from Clinton River in Macomb County, in Michigan, southward and eastward to Ashtabula, in northeastern Ohio, the level of this beach is remarkably uniform. From Ashtabula northeastward to the terminus of the beach near Marilla, N. Y., it rises about 150 feet in as many miles, and in the 75 miles from Clinton River northward to the Ubly outlet it rises about 60 feet. The northward rise appears to be confined to the portion of the shores lying north of a line running from Clinton River near Rochester, Mich., east-southeast to Ashtabula, Ohio. It will be observed that this line, as would be expected, runs at nearly a right angle to the line of uplift mentioned in the discussion of the upper Maumee beach—an uplift which appears to be still affecting the Great Lakes region. (G. K. Gilbert, Eighteenth Ann. Rept. U. S. Geol. Survey, pt. 2, pp. 595–647.)

Lake Warren.

Upper Warren (Forest) beach.—Lake Warren, which succeeded Lake Whittlesey and embraced the waters of both the Erie and the Saginaw basins, came to its level as the result of the withdrawal of the ice sheet from the region between Saginaw Bay and Lake St. Clair. (See fig. 11, p. 11.) The highest beach, also known as the Forest, has an altitude in the Ann Arbor quadrangle of 675 to 685 feet, and at most places in its course stands very near the 680-foot contour. The beach rises northward to an altitude of about 780 feet, which it reaches on the point between Lake Huron and Saginaw Bay, but on passing southwestward from that point to the head of the Grand River outlet it drops to about 680 feet. Indeed, the outlet seems to be a short distance south of the line at which the northward differential uplift sets in. The beach is practically horizontal from the Ann Arbor quadrangle southward and eastward across northern Ohio, but between the Ohio-Pennsylvania line and Batavia, N. Y., it rises about 200 feet, or to 880 feet above sea level.

The portion of this beach within the Ann Arbor quadrangle is exceptionally weak and disjointed. It is weak on the clayey part of the lake border, probably because of shallowness of water off shore. The sandy portions are difficult to interpret. If the entire sandy belt be considered a shore product it would be very strong, but probably a considerable part of the sand was deposited along the border of the ice as it melted back across this region, for a bowldery strip on the eastern border of the sandy belt, seems to mark a halt of the ice at that point. The lake waves and currents may therefore have worked upon sand previously deposited, and the waters in this region being shallow may have been able to produce only disjointed and comparatively weak ridges along the shore.

The duration of the stage marked by the upper Warren beach may perhaps be estimated from the work accomplished by Huron River, which excavated a valley about 1½ miles wide and 15 to 20 feet deep between Rawsonville and the shore of the lake, which is near the eastern edge of the quadrangle. The valley is narrower above Rawsonville but the terrace is traceable at least up to Ypsilanti. The terrace on the north side of Huron River just below Ypsilanti appears to have been cut down several feet below the level of the filling at the Lake Whittlesey stage, and this cutting probably occurred while Lake Warren stood at the level of the upper Warren beach.

Lower Warren beach.—A rather weak beach that stands about 20 feet lower than the upper Warren beach is present in disjointed sections in the southeastern part of the Ann Arbor quadrangle. As it is, however, very sandy and in places has been drifted into low dunes that obscure the old shore line it once represented, its precise tracing is very difficult. In general, however, this shore lies near the 660-foot contour. It is on the whole weaker than the upper Warren beach, and no marked terrace on Huron River conforms with it. The exact point of outlet of the lake that formed this beach can not now be stated. Its waters are thought by Taylor to have stood too low to find an outlet through Grand River. In that case it is likely to have connected with the Syracuse outlet, but its relations to this outlet are not yet determined.

Grassmere Beach.

The Grassmere beach is a sandy strip that lacks the topographic expression of a shore and yet presents remarkable continuity. Like the Arkona beaches it can readily be traced through clay regions because of its sandy character, and like them it maintains the horizontality of a lake shore. It is possible that, like the Arkona beaches, it has been submerged and partly effaced. The lake that formed this beach probably found outlet eastward past Syracuse, N. Y., into the Mohawk Valley, but the full relations of its beach have not yet been worked out nor has positive evidence of its submergence been discovered.

The Grassmere beach stands about 640 feet above sea level in the southeastern part of Michigan but rises above 700 feet on the point between Lake Huron and Saginaw Bay. It is apparently represented in the extreme southeastern part of the Ann Arbor quadrangle by sandy areas in the clay country around the village of Maybee. A strip of sand leading northward from Maybee and passing about one-fourth mile west of the Woolmith quarry seems likely to belong to this beach.

RECENT DEPOSITS.

TERRACE AND VALLEY ALLUVIUM.

Shallow alluvial deposits are found on river terraces connected with the old lake levels. Most of them are sandy and those that open into the old lakes expand into sandy deltas of considerable extent, as is indicated in the discussion of the lake history. The narrow valleys below the level of the terraces also contain shallow beds of alluvial material, though the streams are sufficiently vigorous to carry beyond the limits of the quadrangle much of the material they are transporting. Near the headwaters of the streams, where the gradients are low, fine sediment is being deposited in marshes or lakes along the courses of the streams.

ORGANIC DEPOSITS.

The depressions and poorly drained parts of the quadrangle contain thick beds of muck and peat, which have accumulated through plant growth since the ice sheet withdrew from this region. These deposits comprise not only plant remains but numerous shells of small animals and some bones of large animals. Along the margins of some of the lakes there are also extensive deposits of bog lime or marl, which appear to be due to the growth and decay of organisms which had taken up the lime from the water. The marl deposits are discussed under the heading "Economic geology," but the deposits of muck and peat, though of some economic value, have not yet been developed commercially and will be described here, as will also the fossils that are found in these deposits.

PEAT.

Areas covered.—That part of the Ann Arbor quadrangle which lies above the highest glacial lake level, that of Lake Maumee, abounds in undrained flat areas, slight depressions, and relatively large basins, which are now covered by swamps or lakes. The deeper and larger basins hold lakes, many of them bordered by swamps, marshes, or bogs; while many of the small and shallow depressions have been filled completely through the agency of plants, and present to the eye a flat surface covered by a rank growth of vegetation. The soil below this vegetation is of dark color, or even black, is generally saturated with water from a short distance below the surface, and is nearly or quite devoid of visible mineral matter. This material is commonly called "muck," although the coarser forms of it are sometimes known as "peat," a term that may be as well applied to all its forms, since it grades from one type to another by imperceptible steps. The larger areas of these deposits are shown on the areal geology map.

Since peat has been used for centuries in various parts of the north of Europe, as an efficient and cheap fuel, and since extensive beds of this material occur in this quadrangle as well as in other parts of Michigan, it is described rather fully in this folio.

Physical properties.—Dry peat in its different forms varies greatly in physical properties. In all its forms it is of low specific gravity, weighing from 50 to 55 pounds per cubic foot when taken, without drying, from a well-drained deposit. In color it varies from light brown to black; in texture, from a coarse, rather loosely felted mass of easily recognizable vegetable fibers to a fine-grained, compact, structureless, homogeneous substance, almost as firm and hard as soft coal. Most of the light-brown peats are lighter in weight and coarser in texture than the dark ones, and one deposit may yield all grades, showing a progressive change from coarse to fine, and from light to dark, from the top of the mass toward the bottom. Physical analysis shows that vegetable matter, more or less disintegrated and partly changed in chemical composition, forms the greater part of all peat, for the remains of plants, especially plant cells and fibers constitute the bulk of dry peat. All kinds absorb water readily, and deposits that lie below the surface are saturated with it and are darker in color, much more bulky, and less coherent than when dry. Moreover, the water it holds is given up slowly and, beyond a certain limit, can not be removed by pressure, being held in the cell walls and tissues of the plant remains. Dry peat ignites more or less readily, according to the thoroughness with which it has been dried; burns with a clear flame, and with little smoke (which, however, is increased by the presence of water); and possesses a characteristic pungent odor. If burned in an insufficient supply of air, or with poor draft, it smoulders and remains on fire for an indefinite time, so long as the supply of the fuel is kept up. Kiln-dried peat is hygroscopic, taking up moisture from the air in considerable quantities.

Chemical composition.—From what has been said above of the structure of peat, it is evident that its chemical composition must be variable, since the substance itself is so variable. It is also evident that, since it is largely made up of partly decomposed plant remains, it will have somewhat the same composition as these. Cellulose, or ordinary vegetable fiber ($C_6H_{10}O_5$), and lignin, or woody fiber ($C_{12}H_{18}O_9$), constitute the bulk of the vegetable matter forming peat; these, as the molecular symbols indicate, being made up of three chemical elements, carbon, a solid, and hydrogen and oxygen, both gases. Besides these substances peat contains other chemical elements and compounds, in very small proportion; therefore its ultimate analysis shows the presence mainly of carbon, hydrogen, and oxygen, with greater or less amounts of the ash-forming elements, according to the purity of the peat and the state of its decomposition.

In the breaking down of its vegetable compounds the solid element, carbon, is the one that is least readily built into new compounds, so it is left more and more nearly pure as decomposition proceeds, and as, in its ordinary forms this element is black, the peat thus gradually becomes darker in color because of the increase in its content of carbon in an uncombined or elementary form. Carbon is the chief fuel element, although hydrogen in its uncombined form as well as in combination with carbon, has high fuel value.

By averaging the extremely varying results of numerous analyses and neglecting the ash it is seen that dry peat is composed of four elements, in the following percentages: Carbon, 60; hydrogen, 6; oxygen, 33; nitrogen, 1. It contains more carbon and less oxygen than wood, and about 20 per cent less carbon, 20 per cent more oxygen, and slightly more hydrogen then bituminous coal. Its content of ash varies widely, but in the purest peats is low, running from 2 to 8 per cent. Analyses of four samples of peat from a single deposit, the samples being taken from two holes 300 yards apart, sunk to different depths below the surface, show the following variation:

Content of ash in four samples of peat.

Sample.	Locality.	Depth in feet.	Per cent of ash.
1	1	5	5.70
2	1	10	21.00
3	2	2	4.45
4	2	5	13.00

The ash of pure peat is practically identical in composition with wood ashes, consisting of carbonates of calcium, magnesium, iron, and potassium, with small amounts of sulphates, phosphates, and chlorides. To this, however, is frequently added foreign mineral matter that was washed or blown in from the surrounding region.

Distribution.—In this quadrangle, as in other parts of the temperate zone, peat is found in places where the ground either is or has been saturated with water. Its accumulation is due to the fact that the principal agents of decomposition of vegetable matter are plants of the lowest orders—bacteria and fungi—which require a certain amount of moisture and air. If the moisture present is sufficient to exclude the air, or a large part of it, the number and the activity of these organisms are much reduced, and decomposition proceeds very slowly or is suspended entirely, so that excess of water is one of the conditions necessary to convert ordinary vegetable matter into peat. Where water stands permanently on the surface, or where the water level is normally very near it, if vegetable growth is at all abundant, peat will accumulate until the surface of the deposit is built up so high that water is no longer contained in it in amount sufficient to check the decomposition of plant remains of which it is formed.

Development of the deposits.—Relatively few plants that grow in water are able to live at depths greater than 10 feet below the surface, and those which do grow at such depths contain little enduring vegetable matter. Those which grow at depths between 3 and 10 feet are larger and have more highly developed tissues comprising greater amounts of resistant material, but even these contain little of the firmer mechanical tissues. It is therefore apparent that plants which grow in shallower water and on wet land, or on land lying still higher, must chiefly be concerned in the formation of peat, because other kinds of plants do not supply material of proper kind or in sufficient quantity to form peat deposits. Plants that grow in these habitats are well provided with tough, firm tissues, and are, without doubt, the forms most concerned in peat formation within the Ann Arbor quadrangle.

In discussions of the formation of peat a genus of mosses, *Sphagnum*, is generally said to be the group of plants that is chiefly instrumental in building up the deposits. Within the area under discussion, however, not a single deposit examined has been formed to any considerable degree by this group of mosses, nor is it likely to be an important peat former in this region. It is true that *Sphagnum* is now growing in a considerable number of peat deposits and has built them up to a slight extent since its introduction, but there is no evidence that it was ever present in a much greater number of peat bogs in which the growth of other plants is sufficient to account for all existing accumulations. This subject is fully discussed in a recent publication of the Michigan Geological Survey, and it is sufficient to say here that the peat deposits of the State exhibit a well-marked succession of plants of different types which begins in deep water and proceeds to the shore, each type being controlled largely by depth of water or of the water level in the soil. Each group of these plants, including the microscopic algæ, is instrumental in building up the peat, but, for reasons already given, some are more effective than others, and the kinds that grow nearest the water level apparently contribute the greater part of the material. *Sphagnum* is found on many of the deeper deposits of peat, appearing when the surface of the deposit stands at or slightly above the water level, and it may grow for a time, if conditions are favorable, but usually other and taller plants appear with it, and in many deposits these grow so luxuriantly that the moss is not able to hold its place because of the shade, and soon disappears.

The most important peat-forming plants in this area aside from the aquatic plants growing in shallow water, seem to be the various species of the genus *Carex*, one of the sedges, a group of grass-like plants, differing from the grasses, however, in their manner of fruiting and in having triangular, solid, unjointed stems, while those of the grasses are hollow, cylindrical and have well-marked solid joints. These plants grow in wet places, and are able to form a dense, compact turf by means of their interlacing, underground stems and numerous roots. Growing out from the shore they form a floating mat, in places over the deep water of large lakes, and along the edge of and beneath this mat the peat is built up to a height of 50 feet or more. This bed of peat rises until the mat may become several feet thick and no longer floats, when other plants gain a foothold on it and build up the surface of the deposit a few inches farther, or until it is carried so high above the water level that peat is no longer formed, because of the ordinary drying and decay of the vegetation. If the water is not deep, or if the ground is simply wet, turf-forming sedges may begin their work directly upon it and build up a shallow deposit, which, because of its porosity and the hindrance it offers to the run-off of the water, may be built up several feet, forming a mound or, when it stands on the side of a valley, a terrace.

Mud Lake, in Webster Township, and Dead Lake and some others in Northfield Township, were originally large lakes, which have been partly filled and are still rapidly filling with peat, much of which has been formed along the margin and under a floating mat of sedge. Of the shallower peat deposits, formed on wet and poorly drained areas, the till plain between Whitmore Lake and Ann Arbor furnishes many excellent examples, and some of the peaty areas in the lake plain in the southeastern part of the quadrangle are of similar origin. An interesting series of peat deposits occurs in extensive shallow sheets that overlie the older parts of the marl deposits about Fourmile Lake and the other marl lakes of the northern part of the quadrangle. Peaty terraces occur in the valley of Huron River above Ann Arbor.

At Ore Lake the peat was evidently at one time more extensive than it is at present, as the shores are now being cut back, and the peat beds on top of the marl are sharply differentiated from the marl. It is easy to see, however, that peat grew over the marl gradually, for in places several inches of mixed material lie between the marl and the peat. In the peat over the marl at this place there is a heavy growth of timber. At Fourmile Lake a similar relation of superficial peat to marl beds may be observed in artificial cuts.

Another type of peat deposit, so far as origin is concerned, is that developed on the floors of the broad, gently sloping valleys that served as outlets for the water from the melting ice front during the retreat of the ice sheet. The most notable example of this class is the "celery swamp" south of Ann Arbor, in Pittsfield Township. In these valleys the drainage of the recent past has been so poor that conditions favorable to peat formation have probably existed since the glacial waters ceased to flow through them, and the resulting accumulations have so checked the water which has sought outlet through the valleys that the water level has risen at about the same rate at which the peat was built up. If this hypothesis be correct, it is evident that the conditions here would favor a continued growth of one group of plants, provided the rainfall remained constant and the climatic conditions did not change.

Uses.—Peat has been used in Europe not only directly as fuel, but in other ways and for other purposes. Gas and coke, with various by-products, have been made from it; paper and other fabrics, and certain products used as packing, as bedding for stock, and as the bases for a number of valuable fertilizers are produced from it. In itself, peat is an excellent fertilizer, and many of the small and impure deposits that exist on farms in the region here considered might be used in this way to the great betterment of the light and poor soils adjacent to them, for the material is pure humus, which can be obtained more readily in this way, and at less cost, than in any other. For this purpose it should be composted before using, to insure its complete decomposition.

Peat as fuel.—To be used as fuel, peat must be dried and put into portable form. Many methods for accomplishing these ends have been developed, with the view of producing large quantities of the product, so that a constant supply can be maintained, and in general these methods require elaborate and expensive drying and compressing machinery. The material may be used locally, however, without such careful preparation, by adopting the simple methods of the European peasants, who cut from the deposits peat blocks of fairly uniform size, and stack them up in such a way that they dry in the summer season, after which they are stored under cover. If the material is not of the right consistency in the bog it should be taken out and thoroughly worked until it can be spread into sheets, cut into the desired forms, and left to dry. Freshly cut peat contains from 60 to 90 per cent of water and in drying shrinks from one-half to two-thirds its bulk, and while it will generally hold its form when dry, it is sometimes so friable that it crumbles at the slightest touch. The fuel value of good peat is about three-fifths that of coal, weight for weight, but as ordinarily used, it is probably a more efficient fuel than this ratio would indicate, since a considerable part of the coal is unconsumed, being rejected with the ash and clinkers, while peat is almost wholly burned. Uncompressed peat is not so efficient a fuel as that which has been compressed into blocks of uniform size and density, since these burn more intensely and are much more easily handled.

Amount of fuel in peat.—It is estimated that a single acre of peat 1 foot in depth will furnish from 150 to 200 tons of dry fuel, and that this amount is present for every foot in depth to which the peat extends. From the areal geology map it will be seen that the superficial area of peat in the quadrangle is large, and although careful and systematic borings have not been extended over the entire area some of the deposits are known to reach a depth of 70 feet, and many of them are at least 20 feet deep. In this quadrangle there are at present no establishments for utilizing these peat deposits, but it is reported that an establishment at Chelsea, 1 mile west of the quadrangle, is about ready to put compressed-peat fuel on the market, and as the sources of other kinds of fuel are more and more depleted it is probable that peat will be extensively utilized.

FOSSILS.

The older geological formations that are exposed at many localities in the Southern Peninsula of Michigan contain abundant records of the life of the periods during which they were deposited, but owing to the limited knowledge of the portions of these formations that lie within the Ann Arbor quadrangle it is at this time not desirable to discuss the fossils they contain. So far as known the glacial deposits, which form so large a part of the surface of the quadrangle, are without evidences of animal life. The beds of peat and marl that rest upon the glacial deposits, however, and occupy depressions in their surfaces contain, here and there, a few bones of animals and large numbers of the shells of mollusks.

The bones and teeth of the mastodon have been dug from many of the swamps and peat bogs of Michigan. The most interesting discovery of this nature in the Ann Arbor quadrangle was made a few years since on the farm of Albert Darling, about 7 miles southeast of Ypsilanti, where laborers digging a ditch across a swampy field exhumed several portions of the skeleton of *Mastodon americanus*. The portions of the skeleton obtained were the lower jaw, with molar teeth in place, the left tusk, teeth of the upper jaw, portions of the cranium, together with vertebræ, ribs, and some of the larger bones of the limbs, all belonging to the same individual. The head, after considerable restoration of missing parts, was mounted and is now on exhibition in the geological collection of the University of Michigan.

It may be of interest to the general reader to recall the fact that the mastodon is related to the elephant, but many of the parts of skeletons found show that it was larger than any living elephant. A full grown mastodon is estimated to have been 12 to 14 feet high at the shoulder, and 24 to 25 feet long, measured from the distal end of the tusks to the base of the tail. This animal, now extinct, roamed in large numbers over practically the whole of North America during or after the close of the glacial epoch.

As interesting as the mastodon, and contemporary with it, is the giant beaver, *Castoroides ohioensis* Foster, portions of the skeleton of which have been found in the Ann Arbor quadrangle. A few years ago a nearly complete skull of this animal was discovered beneath about 5 feet of peat by workmen digging a ditch through a celery swamp about 3 miles south of Ann Arbor. The specimen is now in the museum of the University of Michigan. Three molar teeth of the same species were also discovered a few years ago in the excavation for a tile drain in meadow land near the southern boundary of the city of Ann Arbor, between Packard street and the Ann Arbor railroad. *Castoroides* resembles the modern beaver in the structure of its teeth, skeleton, etc., and, as may be presumed, had essentially the same mode of life and habits, but was much larger. The skull referred to, without the incisors, measures 12.1 inches in length, and is 9.6 inches wide in the broadest portion, inclusive of the zygomatic arches. The upper incisor, although broken at the distal end, measured 10 inches along its outer curve, when free from the skull. The corresponding measurement of the skull of a fully grown living beaver (*Fiber canadensis*) are: Length 5.1 inches; width 3.7 inches; and length of upper incisor, when free from the skull, about 2.5 inches. *Castoroides* was more than twice the size of a full-grown specimen of the living beaver, or about as large as a domestic hog. Its remains have been found at various localities from Minnesota to New York and thence southward to the Carolinas and Texas. It lived at the same time as the mastodon, and is now extinct. In the celery swamp south of Ann Arbor, in the same peat deposit that yielded the skull of *Castoroides* described above, but, at a higher horizon, portions of the skeletons of deer, elk, and several domestic animals have been found.

The marl that occurs in several of the lakes and beneath some of the swamps in the Ann Arbor quadrangle contains at some places numerous shells. One of the most instructive localities for obtaining these fossils is the celery swamp near Ann Arbor, mentioned above. In a portion of the swamp beneath about 5 feet of peat there is a layer of white marl of approximately the same thickness which is in many places rich in shells. The species collected at this locality, as determined by Mr. Bryant Walker, are as follows:

Vitrea hammonis (Ström.).
Euconulus fulvus (Müll.).
Euconulus chersinus var. polygyratus (Pils.).
Zonites arboreus Say.
Zonites minusculus Binn.
Zonites fulvus Drap.
Pyramidula striatella Anth.
Helicodiscus lineatus Say.
Polygyra monodon Rack.
Strobilops affinis Pils.
Succinæ avara Say.
Succinæ retusa Lea.
Carychium exiguum Say.
Limnæa desidiosa var. de campii Streng.
Physa elliptica Lea var. (small form).
Physa gyrina Hildrethiana Lea.
Physa ancillaria Say (immature).
Physa integra Hald.
Planorbis campanulatus Say.
Planorbis hirsutus Gld.
Planorbis exacutus Say.
Planorbis parvus Say.
Valvata tricarinata Say.
Valvata tricarinata Say var. compressa Walker.
Valvata sincera Say.

GEOLOGICAL HISTORY.

PALEOZOIC ERA.

SILURIAN SEDIMENTATION.

In the Monroe formation we find the earliest chapter of the sedimentary record that can be read in the rocks outcropping in this quadrangle. The marine shells occurring in these beds indicate that they represent a part of the old Silurian sea bottom. During Silurian time an extensive sea covered all of southern Michigan and a considerable portion of the Mississippi Valley. It extended northward to the Arctic coast and probably beyond. On the northeast it was limited by the Archean highlands of Canada, while to the east and southeast it extended to the coast of Appalachia, a land which lay not far from the present Atlantic border of the United States. The prevailing sediments in this extensive but rather shallow sea formed magnesian limestones. In Wisconsin these limestones reach a thickness of more than 500 feet, uninterrupted by other sediments. The Monroe formation represents a late stage of Silurian sedimentation. The dolomites that compose the bulk of the formation are the result of both the gradual accumulation of organic remains and the chemical precipitation of calcium and magnesium carbonate in the open sea. The deposition of the shore-derived clastic sediments of the Sylvania sandstone member interrupted for a time the deposition of the dolomitic series.

Gradual uplift of the sea bottom brought about the close of Silurian deposition. This elevation continued until considerable areas of the old Silurian sea became land in the regions adjacent to the Great Lakes. Land conditions continued for different periods in different portions of this area, but over much of it they were temporary. The subsidence of considerable areas of the new lands and the return of the sea marked the beginning of the Devonian period.

DEVONIAN SEDIMENTATION.

The Devonian sea differed considerably from its Silurian predecessor in its outlines. It had more of the characteristics of an archipelago. Considerable areas of the old Silurian sea bottom remained as islands or peninsulas in the States adjacent to Michigan during the deposition of the Dundee limestone. The new conditions resulted in the appearance of a Devonian fauna in this region. Nearly all of the molluscan life of the Silurian period had previously disappeared, and new types of marine shells characterize the sediments deposited in Devonian time. So far as can be determined from the fossils thus far found, fishes first appeared in this region during Dundee sedimentation. The almost pure Dundee limestones indicate a sea nearly free from river deposits during the early Devonian. At a later period either a more rainy climate or uplift of the lands surrounding the Devonian sea, or both, resulted in their more vigorous erosion. The soft muds which were brought down by the rivers at this time formed the shale of the Traverse formation.

During the latter part of Devonian time there were many changes in the physical geography of the coasts around this Devonian mediterranean sea. Large areas in northern Indiana and northeastern Illinois which had been above sea level since the close of the Silurian were depressed below sea level. The depression of the coastwise lands was doubtless extensive, lowering the grade of streams and reducing their power of erosion and increasing the fineness of the sediments which they were able to carry to the sea. Extensive marshes bordered the rivers near the sea and added to their fine sediments large quantities of finely comminuted vegetable matter. The fine-textured fissile black Antrim shale was deposited under these conditions. Its black color is the result of the large percentage of organic matter which was deposited with the sediments comprising it. The extreme scarcity of marine life in the sea during the deposition of these beds is in marked contrast with its abundance during the earlier part of Devonian sedimentation. This shale has a wide distribution, extending southward across Ohio and Indiana into the Southern States. It is represented by the New Albany shale in Indiana and by a part of the Ohio shale in Ohio. The deposition of the Antrim shale marks the close of the Devonian in Michigan.

CARBONIFEROUS SEDIMENTATION.

The transition from the Devonian to the Carboniferous period is not marked by any great physical changes like those which initiated the Devonian. There is no evidence in this region of any break in sedimentation at the close of the Devonian period. The rocks show, however, that the sediments became coarser. The coarse sands that formed the Berea sandstone were laid down on the fine argillaceous deposits that formed the Antrim. Sedimentation appears to have gone on without interruption during the period when the Coldwater formation was deposited, probably on a gradually subsiding sea bottom.

The deposition of the Marshall sandstone introduced a change in the nature of the sediments, from mud that formed shales to sands and sandy clays that formed fine-grained and in places argillaceous sandstones. The arenaceous sediments deposited at this time are of very similar character over a wide area. The "Knobstone" of Indiana, a portion of the Waverly of Ohio, and the Marshall sandstone of Michigan all belong to the same general period of deposition, and by the similarity of their physical characters indicate that the physical changes to which they were due were of more than local extent. A moderate elevation of the lands that supplied the sediments, and the consequent rejuvenation of the streams, was probably the cause of the change from the argillaceous sediments of the Coldwater formation to the fine sands of the Marshall sandstone.

The Marshall sandstone is the youngest Paleozoic formation now found in the quadrangle. It is very probable, however, that sedimentation here, as in the central portion of the State, continued a little farther into the Carboniferous. The gradual shallowing of the sea and the development of great marshes, which followed closely its retreating shores, resulted in the contraction of the extensive sea of Mississippian time to a series of great shallow basins, more or less closely connected. Wide, flat sea marshes, where grew the palmlike *Lepidodendron*, stretched along the shores of one of these basins in central Michigan. Gradual uplift of this interior region continued until all of Michigan and the adjacent States of Ohio and Indiana had risen above the sea. With the uplift of the region above sea level began a period of erosion and topographic development which continued until the beginning of the glacial period. This preglacial topography is now completely concealed by the drift, but well records indicate that it was very similar to that of southern Indiana. The Marshall sandstone forms an escarpment similar to that formed by the "Knobstone" north of New Albany.

CENOZOIC ERA.

QUATERNARY PERIOD.

PLEISTOCENE OR GLACIAL HISTORY.

PRE-WISCONSIN STAGES OF GLACIATION AND DEGLACIATION.

Inasmuch as this quadrangle was in the path of the Labrador ice field when it extended farthest southwestward during the Illinoian stage of glaciation, much of the pre-Wisconsin drift has been referred to that stage. Whether the Kansan and pre-Kansan glaciations, which were operative in the upper Mississippi Valley and regions farther north, were also operative here can not be positively stated. The amount of pre-Wisconsin drift, as indicated in the description of the surficial geology, probably exceeds that of the Wisconsin.

On the withdrawal of the Labrador ice field, in the Illinoian stage of glaciation, glacial lakes were probably formed, and the drainage systems doubtless became complex, resembling those that prevailed on the withdrawal of the ice in the later Wisconsin time. Certain deposits of gravel and sand buried beneath the Wisconsin drift are thought to be products of glacial lakes of Illinoian age, but positive statements can not yet be made concerning such features.

WISCONSIN STAGE OF GLACIATION.

The earlier Wisconsin history in this district is somewhat obscure. Whether the Labrador ice field, after its culmination in earlier Wisconsin time, melted back beyond the Ann Arbor quadrangle and permitted glacial lakes to occupy its southeastern portion, as in later Wisconsin time, is not known. There is no doubt, however, that this quadrangle was glaciated in earlier Wisconsin as well as in later Wisconsin time.

The cross striation at the Woolmith quarry and at several points in southeastern Michigan outside of this quadrangle has been interpreted by Sherzer (Jour. Geol. vol. 10, 1903, pp. 194–216) as the work not only of the earlier and the later Wisconsin ice movements but also of pre-Wisconsin movements. This interpretation seems plausible, but in view of complexities of glacial and interglacial conditions, there can hardly be certainty concerning striation produced in pre-Wisconsin stages.

The complex lake history and the drainage development connected with the recession of the Labrador ice sheet in later Wisconsin time are treated at length under the next heading.

DRAINAGE DEVELOPMENT.

Relation of Drainage to Topography.

During and after the retreat of the ice sheet the land was again exposed to rainfall, and the ordinary processes of drainage began again, by which the waters were collected and carried off to the ocean.

Different portions of the drainage systems of this quadrangle and neighboring parts of Michigan exhibit striking contrasts, which are largely the result of topographic conditions produced by the glaciation. The northwestern part of the quadrangle contains fewer streams and more swampy or ill-drained land for a given area than the region along the great Huron-Erie morainic system, which crosses the quadrangle from its northeast to its southwest corner. The scarcity of drainage lines in the northwestern part is due to some extent to its greater proportion of gravelly or loose-textured drift, which readily absorbs rain water and carries it away underground. It appears, however, that the topography has controlled the drainage fully as much as has the texture of the deposits. The morainic hills of the northwestern part, though some of them are about as high as the principal ridge of the morainic system to the southeast, stand in a broad, shallow trough whose slopes are not only very gradual, but are so interrupted by depressions that development of a drainage line in this section is necessarily slow and difficult. The morainic system southeast of it, on the other hand, comprises ridges with slopes sufficiently steep and regular to favor the rapid development of drainage lines. As a result, numerous small lines of drainage lead down these slopes into valley-like troughs that lie between the ridges. The outer slopes of these ridges is generally more abrupt than the inner or iceward slopes, and the streams leading down them are correspondingly shorter. Furthermore their gradients are so steep that the run-off is rapid, and their beds may become dry soon after a rain. The streams on the inner slope maintain a much longer flow, and some are never dry. On reaching the sags between morainic ridges the streams run along them until they find gaps through which they may pass eastward to the lower country. The combination of the portions of the drainage lines along these sags with their small tributary feeders from the neighboring ridges give to the drainage lines a trellised appearance which is a marked feature throughout this great morainic system.

In the lake plain generally a smooth slope was offered for the development of drainage as soon as the lake waters disappeared, and numerous shallow stream channels were soon formed, which took the direction of steepest slope. The Maumee beaches have caused slight divergences and the Whittlesey beach has deflected drainage lines into courses parallel with the beaches and at a right angle with the general course of the streams that flow directly down the slopes. Several of these deflected streams along the Whittlesey beach are about 2 miles long and in conjunction with the direct-flowing streams produce a trellised appearance similar to that produced by the morainic ridges. The course of the deflected portions of these streams is along the landward side of the beaches; or where a beach presents a double ridge or where one ridge laps past another, a stream may flow along the sag between the ridges. Many small streams rise on the lakeward side of each of the beaches and if this fact and the deflections of streams on the landward side are kept in mind the probable position of a beach may be determined from a good drainage map.

A possible effect of delta accumulations on the courses of drainage lines may be seen along Huron River in the eastern part of the quadrangle, and also along Saline River near Milan. The southern tributaries of lower Rouge River have their sources in the sandy districts bordering the Huron east of Ypsilanti and lead directly away from the Huron like the distributaries of a delta, of which they are perhaps an inheritance. This disposition of drainage occurs both above and below the Belmore beach and thus applies to the delta in Lake Maumee and Lake Arkona as well as to that in Lake Whittlesey. The headwaters of Swan Creek, south of the Huron, lead directly away from the river, starting from the large Arkona delta. The scattering of drainage lines in the vicinity of Milan also takes place from the Arkona delta of Saline River.

The drainage of the lake plain bears witness to the recency of its development, for the streams still maintain parallel independent courses for long distances. Streams on the most recent parts of the lake plain, near Detroit River and Lake Erie, show even more marked parallelism than those farther back. The tendency to gather into dendritic systems is just beginning to manifest itself in the higher and older parts of the lake plain.

The drainage development of the lake plain seems, however, to be more largely controlled by the character of the soil than by the topography, development being fuller where a clay soil prevails than it is on a sandy tract. Areas of several square miles in the sandy tracts are traversed by no drainage lines.

Drainage Shifting.

The drainage of this quadrangle has undergone a remarkable series of shiftings in the course of its development, only an outline of which can be given here. By the aid of the sketch maps (figs. 6 to 13), however, the reader may gather the leading elements of the history. These maps serve also to set forth the development of several lines of drainage which lie outside the limits of the quadrangle but to which no reference is here made.

South Bend outlet.—When the Saginaw and Huron-Erie ice lobes were still coalescent over the headwater portion of Huron River a glacial stream that emerged from between the ice lobes near Hamburg made its way westward past Pinckney along a line indicated in fig. 6. This leads through the Portage Swamp to Grand River, thence down the river to Eaton Rapids, thence westward through a channel now occupied by a swamp to Battle Creek at Charlotte, thence down the creek to Kalamazoo River, and thence down the river past the site of Kalamazoo to a narrow lake (the glacial Lake Dowagiac) held in front of the Lake Michigan ice lobe. This lake is one of a chain that extended from the Kalamazoo southward through a strip of lowland now drained by Pawpaw, Dowagiac, and St. Joseph rivers, to South Bend, Ind., where discharge was made into the head of the Kankakee. The drainage then followed the course of that stream to the Illinois and thence to the Mississippi and the Gulf of Mexico. The headwater portion of Raisin River, together with a glacial stream heading in western Washtenaw County, at that time took a northwestward course through eastern Jackson County to Grand River at Jackson, beyond which it soon joined the stream coming in from the Huron Valley through the Portage Swamp and followed the course outlined above.

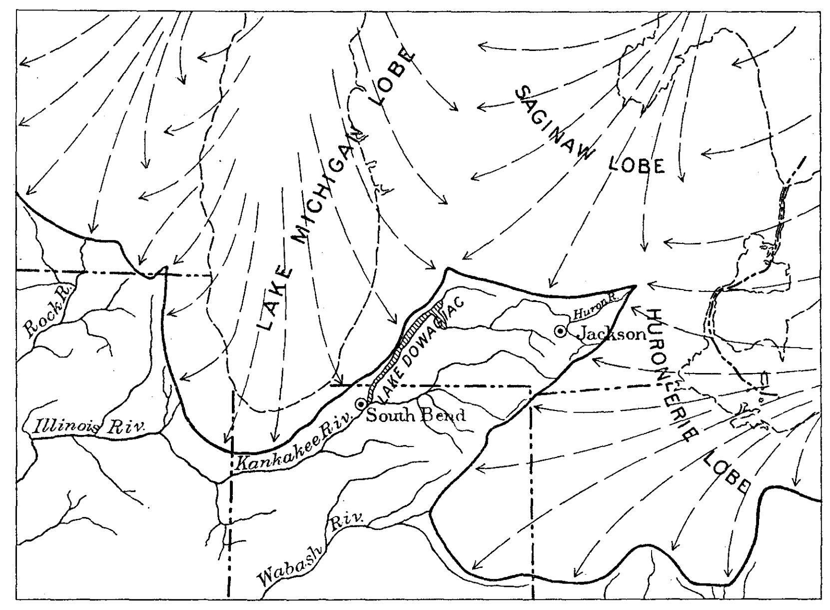

FIG. 6.—First course of drainage from the Ann Arbor quadrangle after the withdrawal of the ice from its western portion, and the position of the glacial lobes. Drainage is through Lake Dowagiac and Kankakee River to Illinois River.

The Chicago outlet.—When by a recession of the ice, the point of junction of the Saginaw and Huron-Erie lobes stood near the head of Huron River, the drainage of Huron and Raisin rivers followed the courses indicated in fig. 7. It coincides with the course previously outlined only to Eaton Rapids, whence, with the northward shrinking of the Saginaw ice lobe, the stream continued northward down the present course of Grand River nearly to Lansing, and thence westward to Thornapple River, the course of which it followed to the bend near Middleville. There it turned southward and led past Gun Lake and through Gun River Marsh to Kalamazoo River. The relations there are not entirely clear, though the stream appears for a time to have turned southward from the Kalamazoo at Otsego and followed Pawpaw River down to Hartford, where it entered a glacial lake bordering the ice edge and representing an early stage of Lake Chicago, shown in fig. 7. This glacial lake discharged through the Chicago outlet from the southwestern edge of the Lake Michigan basin, to the Desplaines and thence to the Illinois, the Mississippi, and the Gulf of Mexico.

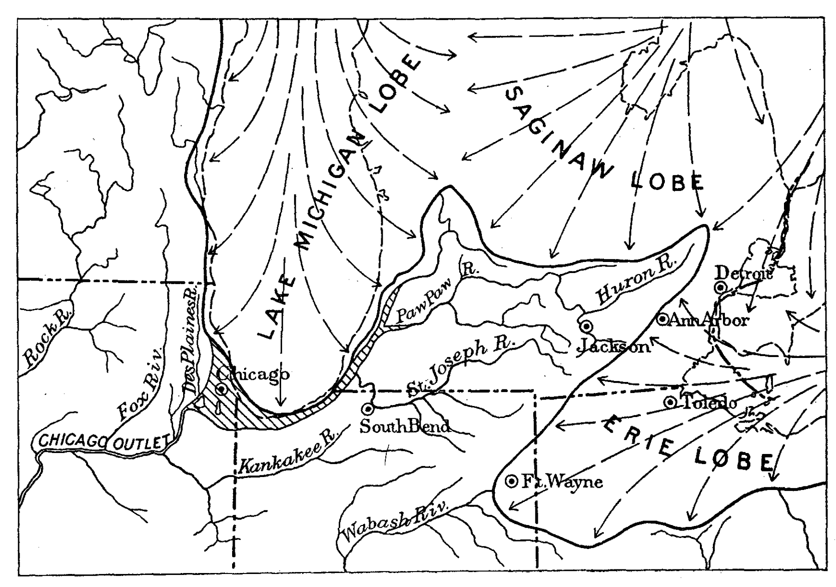

FIG. 7.—Drainage from Ann Arbor quadrangle past Chicago, and the extent of the glacial lobes. Shaded area represents the beginning of glacial Lake Chicago.

The Fort Wayne outlet.—When the Huron-Erie ice lobe had shrunk to about the inner border of the great morainic system that leads across the Ann Arbor quadrangle from its northeast to its southwest corner, Huron and Raisin rivers abandoned their westward lines of discharge and took a southward course to Lake Maumee and thence past Fort Wayne to Wabash River, as indicated in fig. 8. Huron River at that time turned southwestward at Ann Arbor and joined Raisin River in western Bridgewater Township, a portion of its course being through lakelike pools. The terrace at Ann Arbor marking this level of the river is a little more than 840 feet above sea level, or about 80 feet higher than the present river. Much of the headwater portion of Saline River was then embraced in a lakelike pool through which the Huron discharged to the Raisin.

Lake Maumee and the Imlay-Grand outlet.—With the enlargement of Lake Maumee by the withdrawal of the ice sheet came the exposure of the Imlay outlet (see fig. 9), and through that a

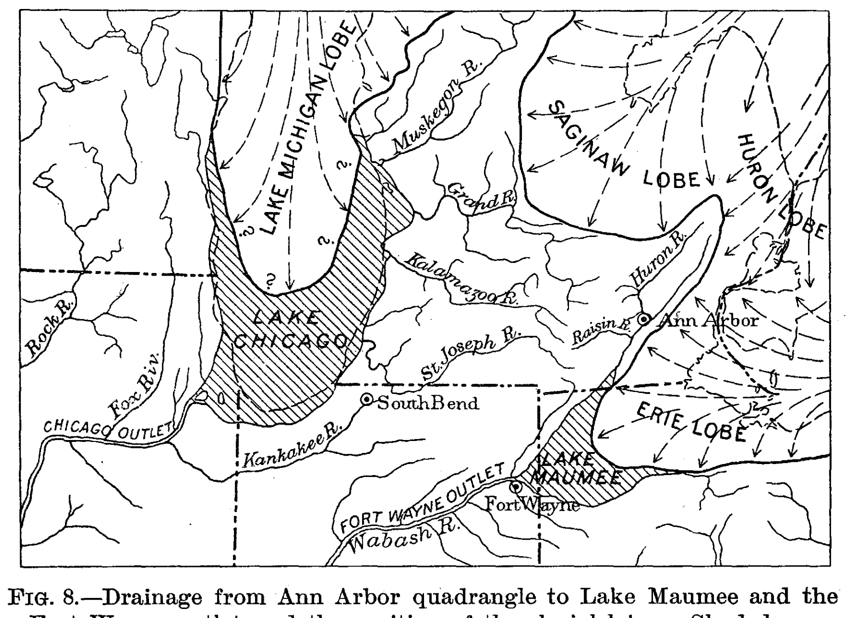

FIG. 8.—Drainage from Ann Arbor quadrangle to Lake Maumee and the Fort Wayne outlet, and the position of the glacial lobes. Shaded areas represent glacial lakes.

slight lowering of the lake level. Lake Maumee then extended up to Ann Arbor, so that Huron River formed a delta at the highest lake level in the northern part of the city, west of Broadway. The delta deposits now comprise horizontal topset beds of coarse material resting on foreset beds of finer material with considerable cross-bedding and a decided dip downstream. Numerous exposures of topset and foreset beds along the bluff west of Broadway show that the growth of the delta began a little farther upstream, perhaps one-eighth of a mile. A terrace that extends down the river to this delta is a marked feature. The terrace and top of the delta stand about 812 feet above sea level, or 30 feet lower than the terrace back of it, which was formed when the river led from Ann Arbor southwestward to Raisin River, as indicated above.

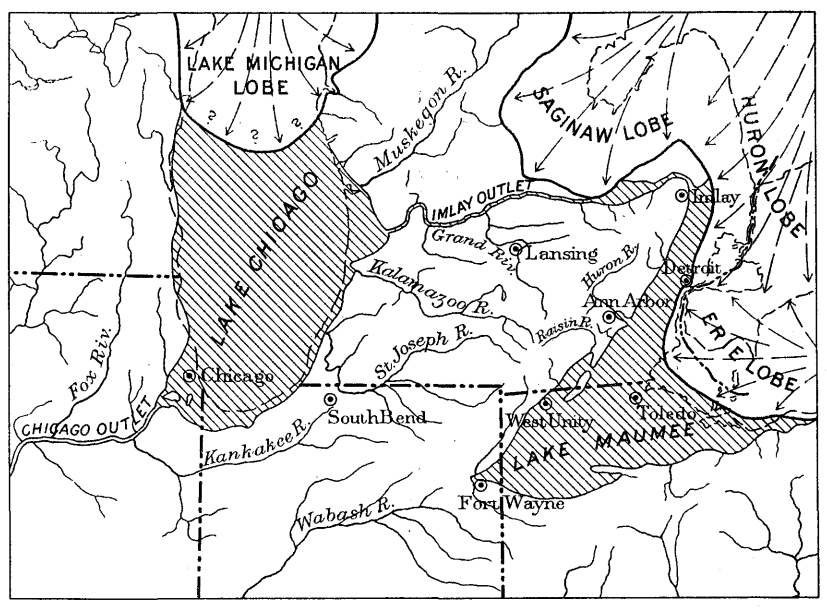

FIG. 9.—Drainage from Ann Arbor quadrangle through Lake Maumee and the Grand-Imlay outlet to Lake Chicago, and the position of the glacial lobes. Shaded areas represent glacial lakes.

At the lowering of Lake Maumee to the level of its second beach Huron River formed a delta at a correspondingly lower level, in the northeastern part of Ann Arbor. This delta is cut into by the Michigan Central Railroad east of the overhead bridge on Fuller street, the cut exposing topset beds of coarse gravel and cobble. When the surface of the lake was lowered to the level of its third beach an extensive delta was formed just east of Ypsilanti.

Raisin River reached slack water at the highest stage of Lake Maumee near Tecumseh. A bed of surface clay that appears in the eastern part of Tecumseh, near the waterworks pumping station, may be a deposit in this slack water.

Saline River at that time entered a bay of Lake Maumee opposite the village of Saline, for at its highest stage Lake Maumee extended over nearly all the territory traversed by the southeastward-flowing portion of the stream.

The middle branch of Rouge River entered Lake Maumee at Northville, just east of the eastern edge of the quadrangle.

Lake Arkona and the Grand River outlet.—With the recession of the ice border northward across the point between Lake Huron and Saginaw Bay commonly known as the Thumb, a passage into the Saginaw basin was opened, and this being much lower than the Imlay outlet the lake level

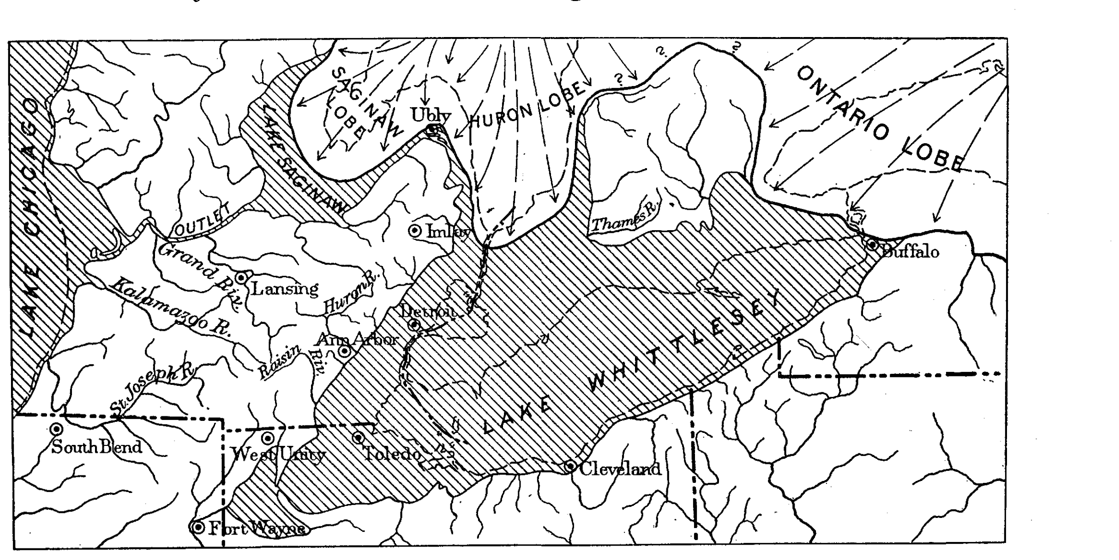

FIG. 10.—Drainage from Ann Arbor quadrangle to Lake Whittlesey and thence by Ubly outlet to Lake Saginaw and by Grand River outlet to Lake Chicago. Also the extent of the glacial lobes. Shaded areas represent glacial lakes.

dropped correspondingly and formed the series of ridges known as the Arkona beaches. In the Ann Arbor quadrangle these beaches stand between 695 and 710 feet above sea level. The lake or lake level that formed them preceded a higher lake level, which will next be considered. The extent of Lake Arkona is not known, for the ice sheet subsequently encroached upon part of its bed. From the Saginaw basin it discharged through the Grand River outlet to Lake Chicago.

Lake Whittlesey and the Ubly outlet.—By a readvance of the ice border southward the passage into Saginaw Bay was closed and the lake level raised sufficiently to discharge past Ubly into the head of Cass River through what is termed the Ubly outlet. The lake level thus established, called Lake Whittlesey, formed a beach, which stands at 735 to 740 feet in the Ann Arbor quadrangle. Its line of discharge is shown in fig. 10. Huron River then extended 2 or 3 miles below Ypsilanti, and its bed was at that time at the level of the terrace on which the high school and much of the business portion of the city is built. The middle branch of Rouge River entered the lake at Plymouth; Saline River entered at York, and Raisin River several miles south of Tecumseh.

Lake Warren and the Grand River outlet.—With a later recession of the ice the glacial lake in the Huron-Erie basin again became confluent with one in the Saginaw basin, as at the time of Lake Arkona, and formed the largest lake of the series, Lake Warren, which discharged directly through

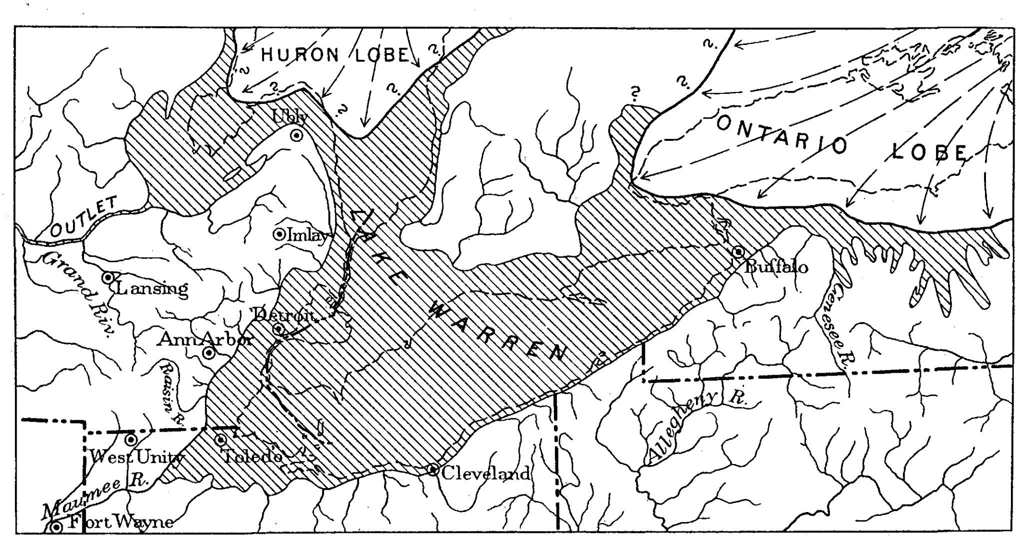

FIG. 11.—Drainage from Ann Arbor quadrangle to Lake Warren and thence westward through Grand River outlet. Also the position of the ice border. Lake area is shaded.

Grand River to Lake Chicago, in the southern part of the Lake Michigan basin, as indicated in fig. 11. In the description of the beaches of Lake Warren it is noted that the upper Warren or Forest beach stands about 680 feet above sea level in this quadrangle and the lower Warren beach about 20 feet lower, also that the fragmentary and washed-down appearance of the lower beach suggests that it may have been formed before the upper beach. If the lower beach is the older the lake that formed it probably found outlet eastward past Syracuse, N.Y., to the Mohawk. A closing of this eastward outlet by a readvance of the ice in the Mohawk Valley and a consequent rise of 20 feet in the lake, to the level of the upper beach, would have caused the outlet to shift to the western end of the lake. The propriety of attaching the name Lake Warren to both these lake levels is questioned, but the introduction of another name for one stage should be deferred till after the clearing away of present uncertainties.

Huron River formed a conspicuous terrace in the eastern part of the quadrangle in harmony with the upper Warren beach. A terrace formed by it in connection with the lower Warren beach is not so conspicuous, a fact which may perhaps aid

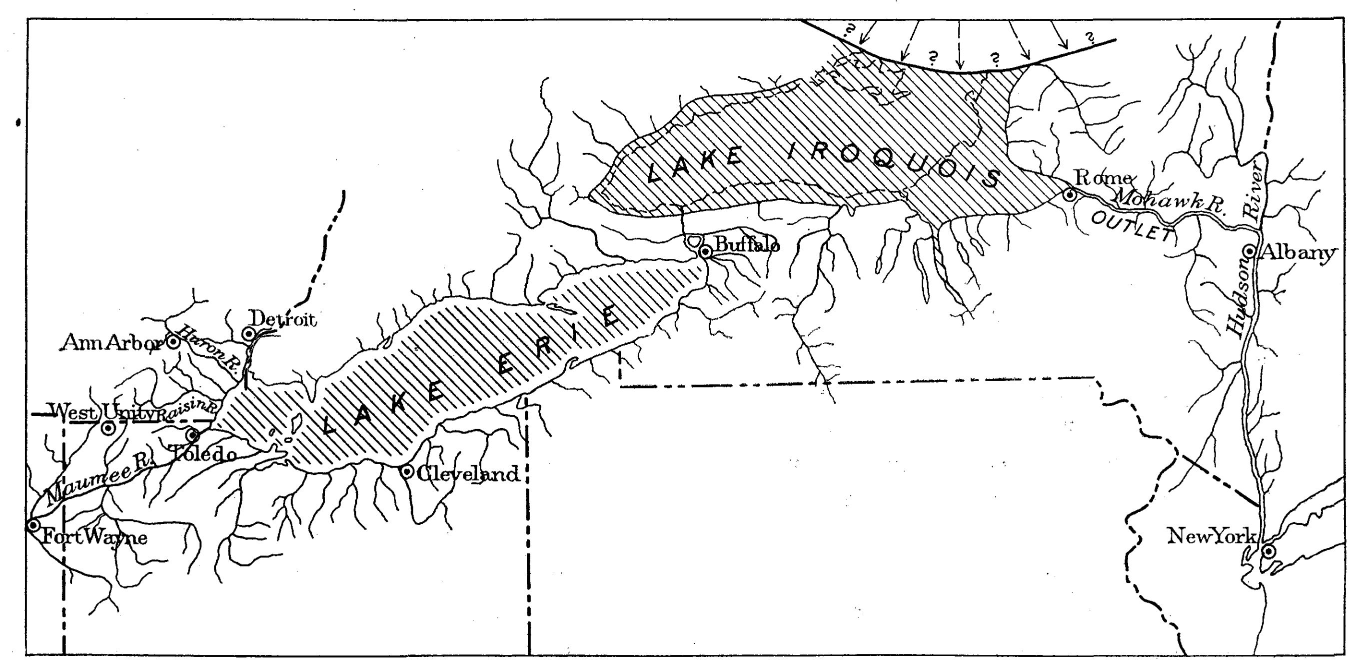

FIG. 12.—Drainage from Ann Arbor quadrangle eastward through Lakes Erie and Iroquois to Mohawk River and thence to Hudson River and the Atlantic Ocean. Shaded area represents glacial lakes. Lake Erie was then smaller than at present but its exact limits are not known.

in interpreting the point in question. At the upper stage the mouth of Saline River was just below Milan and that of the Macon was 2 miles above Azalia, while the Raisin and South Macon, as well as most of the streams in the northeastern part of the quadrangle, were lengthened in districts outside the limits of this quadrangle.

Later stream development. — Concerning later stream development, consequent on the lowering of the glacial lakes by outlets near Syracuse, N. Y., it seems necessary to say a word, although the extension of the drainage lines thus accomplished lay outside the limits of the quadrangle. The opening of these outlets, as described by Fairchild (Bull. Geol. Soc. America, vol. 10, 1899, pp. 27–68), not only caused a lowering of the glacial lake in the Huron-Erie basin but transferred its discharge eastward, so that its waters, which had before been carried to the Gulf of Mexico, were carried to the Atlantic through the Mohawk and Hudson valleys. The level of the water was not lowered at once, but by stages and, as suggested above, there may have been an interruption in its lowering occasioned by a readvance of the ice, by which the lake may for a time have overflowed at the westward outlet. Its beaches are weak, apparently marking stages of short duration. Their weakness may, however, in some places at least, be due to their partial effacement by waves in a later submergence. In southeastern Michigan sandy strips, between the lower Warren beach and the shore of Lake Erie, one of which is termed the Grassmere and another the Elkton beach, were probably formed when the water found outlet near Syracuse.

The discharge through the Syracuse channels was followed by a long-continued discharge past Rome, N. Y., from a lake in the Ontario basin, known as Lake Iroquois, whose extent is shown in fig. 12. Lake Erie then discharged into Lake Iroquois over Niagara Falls as it does now into Lake Ontario. At first it appears to have been much smaller than it is now, being, perhaps, confined to the deep eastern end of the basin. Under these conditions, drainage lines like Huron and Raisin rivers, which enter it from the west, were much longer than the present streams. The lake appears now to be enlarging as the result of an uplift which is raising the outlet of the lake at Buffalo. The uplift now going on may prove to be a continuation of one that was in progress while Lake Iroquois was in existence or it may be a later and independent movement. In either case it will be difficult to outline a shore for Lake Erie that is fully in harmony with Lake Iroquois, for it was the shore of an expanding body of water. For these reasons the map forming fig. 12 does not show a fixed border of Lake Erie at the Lake Iroquois stage.

Soon after the disappearance of the ice sheet from the valley of the St. Lawrence the present system of drainage was established, though the sea for a time extended into the Lake Ontario basin from the Gulf of St. Lawrence. The western part of the present system is shown in fig. 13.

From the sketch of drainage development just presented it appears that the waters of this quadrangle, after traversing successively several lines leading to the Mississippi and the Gulf of Mexico, were transferred to the Atlantic, first by way of

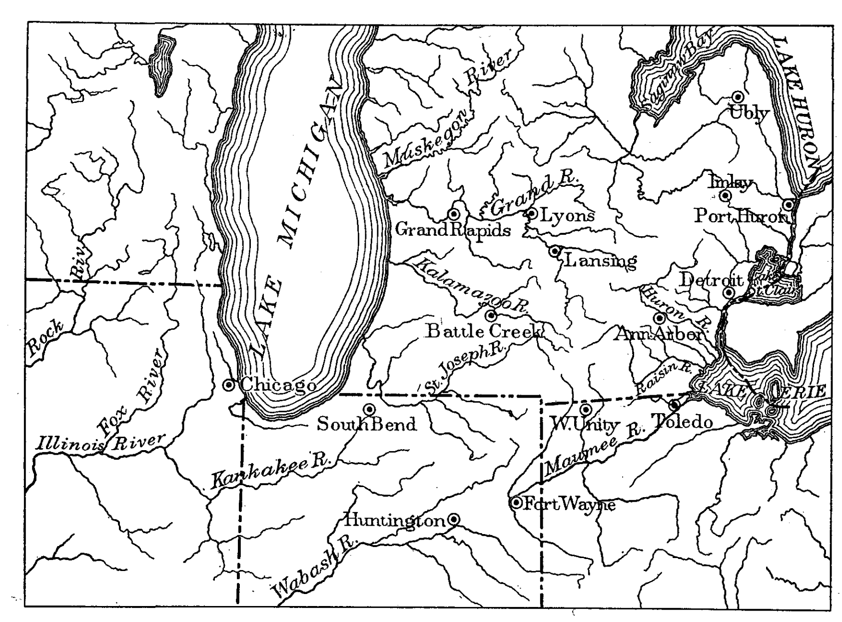

FIG. 13.—Present drainage of southern Michigan and portions of neighboring districts, showing relation to the Great Lakes, which discharge into the Atlantic by way of St. Lawrence River.

Hudson River and later through the Gulf of St. Lawrence. These remarkable shiftings, if analyzed and classified in scientific terms, will illustrate chiefly the first stage of stream development—namely, that of consequent drainage. The several courses taken in turn by the streams were consequent upon the best available slopes. The lake outlets were also the lowest ones available outside the border of the ice sheet. The entire drainage at any particular time was, therefore, consequent upon slopes and available lake outlets, whether by way of the Mississippi, Hudson, or St. Lawrence.

Minor changes.—Many changes in streams within the limits of the Ann Arbor quadrangle have taken place, the most notable being where ponding attended the earlier stages of drainage. For example, Rouge River, which now flows northeastward from Brookville, in eastern Salem Township, traverses a line of glacial drainage that led southwestward past that point. This course of the river has been determined by the northeastward slope of the bed of this part of the glacial-drainage line.

Similarly Saline River flows northeastward from central Bridgewater Township across Saline into Lodi Township, in consequence of a slope in that direction, though the glacial drainage was ponded sufficiently to flow in the reverse direction. Its present southeastward course past the village of Saline into the Lake plain apparently was not due to piracy, for the water seems to have taken this southeastward course because of the steeper slope in that direction, which it was free to utilize as soon as the ice sheet had melted away. Honey Creek flows past Pinckney eastward because that is the present direction of the slope, yet the glacial drainage was in the reverse direction.

It appears that under glacial conditions certain streams flowed along lines that they abandoned as soon as the ice barriers or the pools of water held by the ice disappeared, and that in certain places the bed of a glacial stream has so settled or sunk as to cause a slope in a direction the reverse of that followed by the stream which formed it.

Somewhat different in kind is a deflection of Huron River near Dexter. The river at one time took a southward course from Dexter along Mill Creek and passed eastward through a sandy plain in central Scio Township to its present course just above Foster, thus taking a route about 4 miles longer than the present one from Dexter to Foster. Its deflection to its present course is thought to have been brought about by the deposition of sufficient gravel and sand in the portion of the Huron Valley near Dexter to cause it to flow across a divide at the head of one of its tributaries and appropriate the valley of the tributary to its own use. This is a form of piracy concerning which little has been written, but it is apparently as potent as piracy through erosion, and may find numerous illustrations in glaciated districts.

An interesting case of stream capture noted by Bowman (Jour. Geol., vol. 12, 1904, pp. 326–334), occurred on the borders of the Huron Valley about 5 miles east of Ypsilanti, where Huron River, in broadening its valley, has cut into the middle part of the path of a small tributary running nearly parallel with the main stream. As a result the upper part of this tributary channel now discharges into the river at some distance above the former mouth, and the lower end of the original valley is abandoned.

River terraces and waves of erosion.—In connection with each of the glacial lakes the streams have adjusted their beds to the successive base-levels produced by the lowering and rising of the lake waters. There has also been adjustment by the shifting of streams from indirect to direct courses, as when Huron River changed from an indirect course to Lake Maumee by way of Raisin River and Adrian to that extending eastward from Ann Arbor to the lake border. The bed of Huron River has also been deepened as a result of the shortening of the course below the Dexter deflection just noted.

In the discussion of the glacial lakes attention was called to the occurrence of a terrace on Huron River at Ann Arbor which connects with the upper level of Lake Maumee and stands 25 or 30 feet below the broader valley bed occupied by the stream when it turned southwestward from Ann Arbor to Raisin River. Attention was also directed to a lower terrace at Ann Arbor which conforms with the lower level of Lake Maumee and stands about 25 feet below the terrace formed at the higher level of the lake. There is also a conspicuous terrace on Huron River conforming with the upper beach of Lake Warren from Ypsilanti down to a point near Belleville. A terrace at Ypsilanti should apparently be correlated with the Whittlesey beach, with which it connects about 2 miles below the city. Studies of the valley features have not been sufficiently detailed to justify the complete mapping of each terrace or its coordination with the lake level to which it corresponds, though such mapping and interpretation might be worked out. The sections of other streams falling within the quadrangle show less fully than does Huron River the relation of the drainage to the lake level. The portion of Raisin River within this quadrangle is cut to a depth of but a few feet below the broad plain on which the river flowed when it discharged into Lake Maumee. The headwater portion of Saline River, above the village of Saline, has cut but little into the bed of the pool through which Huron River flowed in its discharge to the Raisin. Below Saline it traverses the old lake plain in a narrow trench of slight depth.

The lowering of the levels of the lakes into which the streams of the Ann Arbor quadrangle discharged increased their gradients sufficiently to cause successive deepenings of the channels, indicated by the terrace just noted. These deepenings, which have progressed headward, are termed erosion waves. None of the erosion waves which started at the mouth has yet reached the head of any main stream. On the Huron the wave has reached only the outlet of Portage Lake. Above that point the stream is filling the basins along its course and erosion occurs in only a few short reaches. On Mill Creek erosion has been confined chiefly to its lower 3 miles, and on Fleming Creek it has occurred chiefly below Dixboro. On the Saline the wave of erosion has barely reached the southern edge of Lodi Township, and on the Raisin it has reached only the Raisin basin in Bridgewater Township. On the headwaters of the Raisin there are, however, longer erosion reaches than on the Huron owing to the much greater fall the stream must make.

RECENT HISTORY.

The changes produced in this quadrangle since the disappearance of the ice sheet and its attendant glacial lakes consist chiefly of changes affecting the basins of small lakes within the morainal and outwash tracts, and of erosion along the water courses. The general surface has been very little modified, and surface weathering has reached a depth of only a few inches. Some of the small morainal lakes have been converted into meadows and quaking bogs, and many have become markedly reduced in area of water surface by the accumulation of marl and peat on their borders. The amount of such filling is indicated in the discussion of these deposits. The work of streams in postglacial time is surprisingly small. The slopes of the main valleys in the higher parts of the quadrangle are dotted with morainal knolls and basins down to low levels, and these features serve to show that only the deeper parts of the depressions through which the streams flow have been worked upon by postglacial streams. These depressions are the result of glacial rather than of fluvial agencies. The amount of postglacial stream work can be best seen in the bottoms of the old lakes Maumee, Whittlesey, and Warren. The depth of erosion there averages greater, however, than in the higher or morainal districts to the west.

ECONOMIC GEOLOGY.

ROAD MATERIALS.

The Woolmith quarry is now being worked chiefly for road material, of which several carloads are removed, crushed, and shipped by rail every day when the quarry is in full operation.

The principal source of road material is gravel, which is found in sizes suitable for use without crushing in nearly every kame or gravel hill, in the Lima esker, and in the Maumee and Whittlesey beaches. The largest pit is that opened by the Ann Arbor Railroad near the northern border of the quadrangle. Gravel has been excavated from hundreds of pits at points where roads cross the line of the beaches or the eskers. Gravel has also been taken from the coarse deposits along the river valleys at a few places, such as the delta of Huron River at Ann Arbor, and the outwash apron south of Huron River. Gravel interbedded with till has been drawn upon for road material at some localities, as in the western part of the city of Ann Arbor and at several points along the edge of the Huron Valley both above and below this city. The good road material available is sufficient in amount to supply all probable needs for some time to come, and is so distributed that it may be obtained within convenient distances for hauling with teams, except in a few townships in the southeastern part of the quadrangle, which can be supplied by the Woolmith quarry, so that no part of the quadrangle lacks good road material.

BUILDING STONES.

Some of the more massive layers of sandy dolomite at the Woolmith quarry were formerly sawed into blocks for use as building stones but most of the rock now quarried there is crushed for use as road material. The principal source of building stones is now found in the bowlders which were strewn over the surface of the Wisconsin drift and which are sufficiently numerous in the northwestern half of the quadrangle to supply the needs of the residents. Most of these bowlders are composed of dense, hard rock—such as granite, gneiss, diorite, quartzite—which, when sufficiently sound, may be broken into nearly rectangular blocks. Blocks of limestone also, many of them of excellent quality for building, are scattered over the surface of the drift or embedded in it at slight depths. These were derived from formations that outcrop in the southeastern part of the State.

Within the last five or six years cement blocks made in part of sand obtained from points near by have been extensively manufactured and used in the cities and villages of this quadrangle, and as bowlders and other building stones become rare this manufacture and use will doubtless become more general. Cement is also now used for making abutments for bridges and other forms of masonry for which field stones or quarry rocks were formerly employed, and is replacing the plank and tar used for sidewalks and the quarry rocks or flagstones used for stepping stones at street crossings.

The Sylvania sandstone reached at a depth of about 50 feet at the Woolmith quarry is well adapted to glass manufacture but is difficult to quarry.

CLAY.

Although clay is abundant in the glacial deposits of the Ann Arbor quadrangle, it is usually of inferior quality for the manufacture of brick or tile, principally on account of the limestone fragments, gravel, and other objectionable material in it. Here and there deposits formed by streams or lakes furnish clay from which brick of fair quality and good drain tile are made. Clays deposited by streams are utilized for brick or tile making at Milan, Azalia, and Exeter, in the southern portion of the quadrangle. Brickmaking was carried on for some years at Ann Arbor, the clay of the abandoned bed of Huron River in the southern part of the city being used. The supply of good material has, however, been practically exhausted. An unsuccessful attempt was made to use the sandy clay of the present flood plain of Huron River above Ann Arbor. A blue fluvioglacial clay on the former line of the Ann Arbor Railroad near Emery, about 7 miles northeast of Ann Arbor, was formerly used in the manufacture of brick, but owing to a change in the location of the railroad the enterprise was abandoned.

The Markham pottery, consisting largely of vases and other decorated wares, is made at Ann Arbor from ordinary till, which by screening and repeated washing and grading is reduced to clay of fine homogeneous texture suitable for making the ware. This pottery was established in 1904 and in two years manufactured about 3000 pieces. The vases are sufficiently porous to absorb considerable water, so that evaporation from the exterior of a vase will keep the water within it cool and prevent the rapid withering of cut flowers.

OIL AND GAS.

Several wells along the line of outcrop of the Antrim or black shale have yielded small quantities of gas, probably derived from the shale, and the supply from some of these wells has been sufficient to warrant piping it into dwelling houses for fuel and lighting, though, so far as known, no well is being put to this use at present. The occurrence of this gas has stimulated prospectors to drill to considerable depths with the hope of obtaining gas or oil in commercial quantities, but none of these efforts have been successful. Their failure is probably due to the absence of anticlinal folds beneath which substances like gas and oil, which are lighter than water, can collect. While these failures are sufficient to show that oil or gas in commercial quantities is not present at depths less than 1500 feet, they leave conditions untested as to the possibilities of their occurrence at greater depths. There is no doubt that the Trenton limestone, which furnishes gas and oil in Ohio, passes beneath the Ann Arbor quadrangle, but what its physical condition and form here may be, whether porous or nonporous, and whether folded or uniformly dipping, is not known.

MARL, OR BOG LIME.

GENERAL STATEMENT.

The portion of the Ann Arbor quadrangle outside the bed of Lake Maumee, as has already been noted, comprises many basins that now hold lakes or swamps. In these depressions two classes of postglacial deposits of high economic value have been formed through the agency of plants, namely peat and so-called marl. The peat deposits are described in a separate section of this folio. The principal deposits of marl are in Zukey, Bass, Portage, Ore, and Fourmile lakes and their associated marshes, and also in several other lakes, at places indicated on the areal geology sheet, and beneath peat in certain of the marshes, as, for example, in the celery swamp 3 miles south of Ann Arbor. Except in the five lakes named, the marl does not occur in sufficient quantity to be commercially valuable, although it has been at some places used as a fertilizer or burned to lime for local consumption. Deposits of marl similar to those just mentioned are abundant throughout the Southern Peninsula of Michigan, and the following account of their character and origin is based on examinations made at many places.

PHYSICAL CHARACTERISTICS.

When free from sand, clay, and other mechanical impurities the marl is normally a fine, soft, plastic, mudlike material, cream, white, or gray in color, and crumbles to a fine powder on drying. The only known deposit of marl that does not show the characteristics just mentioned occurs about the border of Ore Lake, where the marl above low-water level is in part cemented into an open-textured, conglomerate-like rock, which forms beds 6 to 10 or more inches thick. Two principal varieties are recognized, namely, white marl and grey marl, but the distinction between them is due principally to variations in the amount of organic matter present and is not important.

The marl at most places contains shells of fresh-water mollusks, but these seldom constitute more than 5 to 10 per cent of its volume and therefore do not justify the term "shell marl," sometimes applied to it. Entire shells are present at the surface of many of the deposits, but at a depth of a few inches only fragments are usually discernible, and at depths of 10 to 15 feet the shells are completely disintegrated.

The physical character of marl may be shown by washing it on sieves of various-sized mesh. Two representative samples, one of white and the other of gray marl, sifted in this manner through sieves ranging in fineness from 12 to 200 meshes to the linear inch, gave the results tabulated below, which serve to show the general physical character of the marls of Michigan. The samples chosen,

Mechanical analyses of marl.

	1. White marl.	2. Gray marl.
Residue on 12-mesh sieve	----------	1.62
Residue on 50-mesh sieve	1.93	12.44
Residue on 100-mesh sieve	6.50	16.55
Residue on 200-mesh sieve	7.99	11.76
Material passing through 200-mesh sieve	83.66	56.63
	100.08	99.00

however, were free from large shells, such as occur at or near the surfaces of some marl beds and did not contain concretionary nodules of the nature described below. Of the samples subjected to mechanical analysis, the results of which are given below, No. 1 is white marl from Lake Wetzel, in Antrim County, and No. 2 is gray marl from Goose Lake, in Lenawee County, but less detailed examinations of many deposits, including those of the Ann Arbor quadrangle, show that they are of the same general character as those here considered.

On examining the fractional portions of the marl thus obtained with the aid of a microscope, it was found that the coarser particles consisted principally of fragments of circular tubes with striated walls, such as might have been produced by the deposition of crystalline grains about vegetable stems. Much of the finer material, down to that caught on a 200-mesh sieve, consists of fragments of tubes, evidently of the same character as those found in the coarser portions. The finest particles of all, are amorphous grains, in which no organic structure is apparent. Precisely similar particles, however, were obtained by pulverizing the material caught on the coarser sieves. The evidence obtained by mechanical analysis shows that the marl, with the exception of from 5 to 10 per cent of shell fragments, is essentially of the same character throughout, and has a structure suggestive of vegetable origin. A more detailed account of the examination just referred to may be found in the Twenty-second Annual Report of the United States Geological Survey, for 1900-1901, part 3, pages 653-657.

Many of the marl deposits in Michigan such as those on the shores of Bass, Portage, and Ore lakes, consist largely of round or oval pebble-like masses, the largest about 1 inch in diameter, most of which are soft enough to be crushed in the hand. When broken they exhibit a concentric structure, and many of them contain, at the center, a fragment of a shell or other hard body about which deposition took place. These concretionary masses are abundant in the surface portion of some marl beds, but at depths of 10 to 20 feet are more or less disintegrated. When fresh samples of these pebbles are treated with dilute acid, the calcium carbonate of which they are principally composed is dissolved, leaving a pulplike mass of vegetable fibers, filamentous algæ.

Mingled with the concretionary pebbles just described, and also scattered over the surface of many marl deposits are shells, particularly the valves of unios or fresh-water mussels, bearing irregular incrustations of calcium carbonate, which on some shells is 1 inch or 2 inches thick. These masses are of the same character as the marl pebbles, and the association of algous growths with some of them is apparent.

CHEMICAL COMPOSITION.

Chemical analyses of a large number of samples of marl from various localities in Michigan show that when free from sand, clay, or other extraneous matter it is nearly pure calcium carbonate, but contains a small percentage of magnesium, and of sulphur. Representative samples of marl collected at localities in the Ann Arbor quadrangle, show the composition indicated in the following table:

Chemical analyses of marl.

[Samples dried at 100° C.]

Constituents.	1.	2.	3.	4.	5.
Silica (SiO_2)	6.66	0.96	0.48	2.65	0.53
Alumina (Al_2O_3)	3.17	--------	} 1.02	1.40	.14
Ferric oxide (Fe_2O_3)	1.36	.62			.99
Calcium oxide (CaO)	47 09	52.60	51.27	49.17	51.87
Magnesium oxide (MgO)	1.77	1.79	1.23	1.42	1.10
Sulphuric anhydride (SO_3)	1.25	.58	.52	.82	.14
Loss on ignition	40.70	43.45	45.82	44.66	44.46
	100.00	100.00	100.34	100.12	99.23
Calcium carbonate ($CaCO_3$)	84 09	93.92	91.56	87.80	92 63
Magnesium carbonate ($MgCO_3$)	3.72	2.76	2.57	2.96	2.30

1. From Fourmile Lake. Analyst, E. D. Campbell.
2. From Zukey Lake. Analyst, E. D. Campbell.
3. From Zukey Lake. Grade A. Analyst, H. W. Berger. Average of over one hundred analyses made by the National Portland Cement Company.
4. From Zukey Lake. Grade B. Analyst, H. W. Berger.
5. From Ore Lake. Analyst, E. C. Sullivan. In order to make this analysis uniform with the others in the table, under "loss on ignition" is included: CO_2=42.30; combined water=1.22; and absorbed water=0.97; the complete analysis also contains: Na_2O=0.10; K_2O=0.10; and MnO=trace.

MODE OF OCCURRENCE.

The marls of Michigan, according to Charles A. Davis, have been formed mainly through the vital action of plants, and particularly of certain algæ, which separate calcium carbonate from the water in which they live and deposit it in their tissues and on their surfaces. The plants most active in this process are the Characeæ, especially *Chara fragilis*, or common stonewort, and the smaller blue-green algæ *Zonotrichia*. These plants, but particularly *Chara*, grow luxuriantly in water that is from a few inches to about 25 feet deep, and when they die the calcium carbonate they have secreted remains on the bottom. In this manner and also by the drifting of dead plants by wind and currents, thick deposits of marl are accumulated near the margins of lakes while but little such deposition takes place where the water is over 25 feet deep. These facts explain the occurrence of terrace-like deposits of marl about the borders of deep lakes, as, for example, Zukey, Bass, Portage, and Ore lakes, while their bottoms, beneath deeper water, are nearly free from similar material.

An important fact to be noted in this connection is that marl is deposited only in lakes in which the percentage of lime salts in solution is far below the point of saturation. Many of the marl-depositing lakes have outlets, and their waters are of the usual purity of the streams of the region where they occur. That is, they contain about 0.357 parts per thousand of total solids, and about 0.113 parts per thousand of calcium carbonate in solution. Owing to the small percentage of calcium carbonate present in these waters and the absence of conditions leading to a marked degree of concentration by evaporation, no explanation can be suggested for the formation of marl by chemical precipitation. The cementation of the marl about the border of Ore Lake, referred to above, seems to be due to the evaporation of the water drawn up by capillary attraction above the level of the lake and the precipitation of the salts it contained.

USES.

Marl is of value as a fertilizer and if mingled with the peat that occurs in many lakes and swamps in intimate association with it might be applied with great benefit to cultivated fields or grass land, but it has been used for this purpose in Michigan to only a limited extent. The analyses given above show that it is nearly pure calcium carbonate and if calcined would yield a superior quality of lime. It has been burned for lime in a small way at several localities in Michigan; and Limekiln Lake, in the Ann Arbor quadrangle, derives its name from the fact that the marl it contains was formerly burned to lime. The difficulties in the way of manufacturing lime from marl are the large quantity of water to be evaporated and the inconvenience of handling finely divided material in the kiln. Several of the smaller marl deposits in the Ann Arbor quadrangle, it is to be hoped, will in future be utilized in ways just referred to.

When it occurs in large beds of sufficient purity marl is chiefly available for the manufacture of Portland cement. The large cement industry recently developed in the Southern Peninsula of Michigan is based on the marl deposits found there. (Russell, I. C., The Portland cement industry in Michigan: Twenty-second Ann. Rept. U. S. Geol. Survey, pt. 3, 1902, pp. 629-685.)

AVAILABLE DEPOSITS.

Within the area of the Ann Arbor quadrangle there are two marl deposits of sufficient extent and purity for commercial use, namely, the bed of Zukey and Bass lakes, and that of Fourmile Lake. The marls in Portage Lake and Ore Lake and their associated marshes are also extensive and may perhaps be considered as additional deposits of commercial importance.

Zukey and Bass lakes.—The deposits of marl in Zukey and Bass lakes and their associated marshes are types of the beds in Southern Michigan, and the following facts concerning them, together with the analyses already presented, have more than local interest.

The marl in Zukey and Bass lakes occurs for the most part in terrace-like extensions from their shores, which have a depth of 8 or 9 feet of water on their outer margins and descend steeply into water that is from 25 to 30 feet deep. A little west of the center of Zukey Lake there is a shoal, oval in shape, measuring about 200 by 600 feet, which contains marl that ranges in depth from 14 to 22 feet and is surrounded by water from 22 to 25 feet deep. Between these two lakes is a channel representing a much smaller lake, now almost completely filled with marl and known as Lime Bay. The marl in these basins, which is essentially a single and nearly continuous deposit, has been carefully surveyed by the National Portland Cement Company, which owns the deposit.

The area surveyed was divided into squares measuring 100 feet on a side, and the quantity and quality of the marl in each square was carefully determined. In classifying the marl four grades of purity were recognized, indicated by the letters *a*, *b*, *c*, *d*. The poorest marl, grade *d*, is found near the shore of the lake and in a general way the other grades are arranged in succession lakeward from it; the purest having been deposited farthest from sources of mechanical contamination. Grade *a* and *b* are well suited for making Portland cement, but grade *c* is not considered serviceable for that purpose, and grade *d* is worthless.

Measurements of marl in Zukey and Bass lakes and Lime Bay.

Place.	Quality.	Area.	Average depth.	Depth of water.
		Sq. feet.	*Feet.*	*Feet.*
Zukey Lake	*a*	380,000	19.0	3.5
Do	*b*	1,630,000	18.0	4.8
Do	*c*	540,000	16.8	3.8
Do	*d*	120,000	15.0	3.2
Bass Lake	*a*	2,370,000	19.4	3.2
Do	*b*	770,000	20.6	3.7
Do	*c*	90,000	18.1	3.8
Do	*d*	70,000	14.3	2.4
Lime Bay	*a* and *b*	320,000	17.3	2.0
		6,290,000	18.6	3.7

The average composition of the grades of marl designated as *a* and *b*, as indicated by a large number of analyses, is shown by the analyses already given.

In addition to the portions of the deposit surveyed there is an extension westward in Lime Lake, which, however, is comparatively small in area. As shown by the measurements given above, Zukey and Bass lakes and Lime Bay contain approximately 103,000,000 cubic feet of marl. If 9 cubic feet of marl as it occurs in the bed will make one barrel of Portland cement—a reasonable estimate—the amount available is sufficient to manufacture about 11,500,000 barrels of cement.

Fourmile Lake.—The only place at which the marl beds of this quadrangle have been utilized for cement making is near Chelsea, where the White Portland Cement Company for a time made cement from the marl beds in and about Fourmile Lake. Though not so extensive as those on Zukey and Bass lakes they are yet of sufficient extent to furnish material for running the plant many years. Not many data of value could be obtained from the company concerning the marl deposits. It is worthy of mention that the clay used by this plant in cement making was obtained from a glacial deposit in the marsh bordering the lake. The clay bed is reported to have a thickness of over 50 feet, and although it is a glacial clay it contains remarkably few pebbles and otherwise seems well adapted for use in cement making.

SOILS.

The drainage conditions attending the melting of the ice, and the presence of lakes on portions of the surface after the ice had disappeared were potent influences in determining kinds of soil. Where the water had free escape from the melting ice the soils are loose textured or even gravelly, but where the escape of water was impeded and was therefore slow the soils are close textured and in places almost impermeable to water. On the lake bottom the soils range from loose-textured, gravelly material at deltas and at the successive shores of the falling lake to a stiff clay that is fully as close textured as any of the glacial deposits. A sandy soil which is intermediate in texture between the gravel and the clay covers a large area in the southeast part of the quadrangle. It would be difficult to map the extent of each class of soil. Over wide areas, particularly in the interlobate moraine, the soil is subject to frequent changes, which make detailed mapping impracticable. There is also more or less gradation or intergradation of soils. Thus in the predominantly clay-loam areas the clay and clay loam ranges to sandy loam; while in the sandy-loam areas there is a gradation in one direction into clay and in the other into sand or gravel. The nearest approach to uniformity is found in the sands and clays of the beds of the glacial lakes.

With the exception of the sandy tracts the soils are generally productive. Probably the sandy tracts would bring larger returns if reforested than can be obtained by farming. The steep-sided hills of the moraines are available for peach growing, for orchards planted on them generally escape damage from late spring frosts.

WATER RESOURCES.

WATER POWER.

Degree of development.—This quadrangle includes the portion of Huron River in which water power has been best utilized as well as a section of Raisin River that affords important sources of power. Within the limits of the quadrangle, ten dams are in operation on the Huron and several small water powers have been developed on tributaries of the Huron and on Saline River, a tributary to the Raisin.

The development of water power within the Ann Arbor quadrangle is already large, but it is capable of considerable increase and improvement. A survey made under the direction of Lyman E. Cooley, in the interests of the Washtenaw Light and Power Company, for the purpose of increasing and more economically utilizing the water power on the Huron, has recently been completed, and certain of the data thus obtained have been furnished by the company for use in this folio and are here presented.

Huron River.—Huron River affords great advantages for water-power development in the arrangement of its tributaries, the location of lakes or natural storage reservoirs in its drainage area, and the distribution of its fall. Its headwater portion, above Portage Lake, in a table-land that stands about 850 feet above sea level, includes numerous lakes and receives several important tributaries. The greater part of the drainage basin of Mill Creek, which enters the Huron at Dexter, is a similar elevated table-land. Of the 900 square miles embraced in the watershed about 520 square miles fall within the limits of the headwater table-land, 16 between Portage Lake and Dexter, and 143 in the Mill Creek watershed, making a total of 679 square miles above Dexter. The Huron at Dexter flows at an altitude 830 feet above sea level or 256.65 feet above the mean level of Lake Erie. It thus appears that the stream leaves Dexter with the accession of more than 75 per cent of the drainage to furnish power in a somewhat rapid descent of more than 250 feet to Lake Erie. The stream falls 190 feet before it leaves the Ann Arbor quadrangle, being below 640 feet at its eastern limits.

The following summary of gradients on Huron River in its course across the quadrangle has been obtained from a profile included in Mr. Cooley's report on the survey of the Huron River, supplemented by estimates between Ore Lake and the Hudson dam.

Summary of gradients on Huron River, in feet.

Stations.	Altitude above sea.	Distance to next point.	Fall per mile.
Ore Lake	855.6	[1]52,800	0.51
Portage Lake	850.5	[1]11,560	6.
Hudson (under dam)	838.5	19,200	1.82
Dexter dam	831.86	1,500	10.42
Dexter bridge	828.9	13,600	3.47
Scio dam	819.06	11,000	5.117
Delhi dam	808.4	17,400	6.76
Foster bridge	787.12	11,200	5.1
McMahon rapids	776.3	1,300	19.17
Foot of rapids	771.39	10,300	3.9
Base of dam	763.16	11,700	6.875
Railroad bridge	747.93	5,800	4.63
Highway bridge	742.96	9,300	7.38
Geddes (under dam)	729.96	13,200	6.9
Lowell (under dam)	713.39	22,700	10.88
Foot of Ypsilanti rapids	676.	41,500	4.04
Rawsonville	644.18	--------	--------

[1] Estimated.

The rapid fall for 4 miles in the vicinity of Ypsilanti affords power for five dams with heads of 16, 12, 9, 5, and 6 feet. But from Ypsilanti to Belleville, a village about 1 mile below the point where the river leaves the quadrangle, no power is utilized, although at one time a mill at Rawsonville used water power. Dams are in operation at date of writing (April, 1905) at Geddes, Ann Arbor, Osborns Mill, Delhi Mills, and Hudson Mills, with heads of 10, 8, 6, 10, and 9 feet respectively. At Dover, Dexter, Scio, and Foster the dams are either out or are in disuse.

The minimum flow of the river at Dexter is estimated by Cooley to be 82.5 second-feet, which corresponds to about 61 at Hudson Mills, 92 at Geddes, 100 at Rawsonville, and 109 at Flat Rock, near the mouth of the river. It is further estimated that an average minimum of less than 100 feet for 30 days at Dexter will probably not occur once in a generation, and this may be taken as a normal minimum for dry years. The ordinary low-water flow is more than double that amount. The survey by Cooley shows that it is feasible to impound the water in the table-land so as to furnish a flow which will not fall below 240 second-feet and which by good management may yield 360 second-feet at Dexter. It also shows that it is feasible to operate 10 dams, each 21 feet high, in the section from Dexter to Rawsonville. The present dams will probably soon be supplanted by higher ones.

Tributaries of Huron River.—On tributaries of Huron River dams are in operation as follows, the data having been furnished by the mill owners:

Utilized water powers on tributaries of Huron River.

Location of dam.	Rated horse-power.	Maximum head.
		Feet.
South Fork at Rushton	40	14
School Creek at Pettysville	19.5	18
Hamburg Creek at Hamburg		
Honey Creek at Pinckney	60	14
Mill Creek at Dexter	116	10.5
Mill Creek in sec. 29, Lima Township	20	8

Raisin River.—Raisin River has no great ingathering of drainage into its headwater portion, but receives several large tributaries in its middle course, below the section traversing the Ann Arbor quadrangle. The river drains only 160 square miles above the point where it enters the quadrangle, but between that point and Tecumseh, where it leaves the quadrangle, its drainage area increases to 250 square miles, the increase being due chiefly to two affluents, Iron Creek and Evans Creek, the latter entering within the village of Tecumseh. This headwater portion of Raisin River falls from about 1100 feet at its source to 844 feet at the point where it enters the quadrangle and makes an additional fall of 100 feet, or to 744 feet, in passing to the southern limits of the quadrangle, at Tecumseh. In this headwater portion, as in the headwater portion of the Huron, there are numerous lakes and extensive gravelly plains, which receive the surface water and to some extent the underground drainage and regulate the distribution of the water to the streams.

Saline River.—Saline River, the most important tributary of Raisin River, drains an area of 130 square miles, of which 80 square miles lie above Saline village. Its most rapid fall occurs in the vicinity of Saline, where it makes a descent of 60 feet in about 3 miles, thus affording good water power, supplied from nearly two-thirds of the watershed. It descends 64 feet within a distance of 13 miles, from its source in Columbia Lake to the 800-foot contour, and its descent from the 800- to the 700-foot contour covers 10 miles, leaving about 22 miles for the descent of 66 feet in its lower course. Although there are but two developed water powers on the river, one near Saline and one at Milan, the amount of its fall would justify several similar powers.

Water powers on Raisin River and its tributaries in or near the Ann Arbor quadrangle.

Location of dam.	Rated horse power.	Maximum head.
		Feet.
Raisin River in sec. 29, Sharon Township, Washtenaw County	75	6
Raisin River at Manchester	85	12
Raisin River at Manchester	135	14
Raisin River in sec. 20, Bridgewater Township, Washtenaw County		9
Raisin River at Clinton		8
Raisin River at Tecumseh	150	18
Evans Creek at Tecumseh, same mill as last		18
Spring Brook, 1 mile south of Saline	40	12
Saline River, 1½ miles south of Saline	45	9
Saline River at Milan	70	7

UNDERGROUND WATERS.

Drainage.—The soil in the quadrangle is so porous, except in certain small areas that are covered by a stiff clay, that it absorbs a large part of the rainfall. It is roughly estimated that less than 20 per cent of the rainfall escapes absorption and may be reckoned as surface run-off. On many of the steep hillsides the water is so rapidly absorbed that gullies have not been developed, while on the plains or gently undulating tracts, there are areas, some of them comprising several square miles, in which scarcely any drainage lines have been developed, and yet the soil is so well underdrained that it forms good farm land. Indeed, swamps are much more numerous and extensive on the borders of the streams and lakes than elsewhere, as may be seen by a glance at the topographic map. The divides and slopes absorb the water and supply it by slow underground drainage to the streams or lakes and their bordering swamps.

Ground-water table. — The ground-water table conforms in a general way to the surface of the land, as is shown by data afforded by wells, but stands in places considerably below the surface and yet somewhat above the neighboring swamps. Thus, on some of the high ridges in northeastern Lodi Township the permanent ground-water table is fully 100 feet below the surface. Such conditions are, however, exceptional and are restricted to places where the ridges are composed of porous beds to that depth. As a rule the distance to the ground-water table is less than 25 feet and at few places exceeds 50 feet. On the till plains, and to some extent on the plains of sand and gravel, and also on the moraines, the ground-water table rises and falls with the wetness or dryness of the season, so that wells not infrequently show variations of several feet in the depth of water as a result of the ground-water fluctuations.

Water with strong hydrostatic pressure.—Wells and other excavations have shown the presence of water under two very distinct conditions, one marked by hydrostatic pressure or artesian head under which the water rises in the pipe or well, the other showing no such pressure or rise. Waters under strong hydrostatic pressure are generally confined between beds of clayey till or other nearly impervious material, the upper bed acting as a cover to prevent the escape of water upward as well as access by direct percolation downward. The movement of the water that is without notable hydrostatic pressure is usually toward neighboring streams, while that in which there is strong hydrostatic pressure is as a rule largely independent of the surface drainage.

On the artesian water map the head in the wells that show strong hydrostatic pressure has been plotted and the result exhibits an increase in artesian head from the northwest toward the southeast, which indicates that the high land at the northwest constitutes a catchment area from which the water passes southeastward beneath the lower districts. The glacial deposits are so complex, however, as to preclude the assumption that a widespread continuous water-bearing bed is present throughout the quadrangle. It is more probable that the water beds are distributed in strips or sections of irregular thickness and width, and that in some places the beds have no adequate underground passages through which the water may find escape.

In small districts where the surface is sufficiently low, flowing wells have been obtained. The public supply of Ann Arbor and of Ypsilanti is derived from wells of this class, but as a rule the water under hydrostatic pressure fails by a few feet to reach the surface. The distribution of the wells and the areas where flowing wells have been obtained are shown on the artesian water map. Some of the artesian-well districts are supplied, in part at least, from catchment areas near by, which stand but little higher than the wells, and for this reason, probably, the water in these wells rises but little higher than the surface or well mouth. The Ann Arbor Water Company at one time pumped so vigorously from one of its large wells as to drain the shallow wells in the neighboring districts out to a distance of about one-fourth mile, thus showing that these wells are supplied, in part at least, from the immediate vicinity. Yet some of the wells are 75 to 90 feet deep and pass through a bed of blue till before finding water. The wells that were drained by the heavy pumping, however, do not pass through till, their entire depth being through sand and gravel that would readily absorb the surface water. These shallow wells stand on higher ground than the flowing wells and the water in them causes hydrostatic pressure in the inclined beds which lead down from them beneath the till to the flowing wells. A narrow flowing-well district lies south of Ann Arbor, in the line of glacial drainage already described, which led from Huron River to Raisin River. The wells here are very shallow, most of them being but 20 to 30 feet deep, and the water rises only 2 to 10 feet above the surface. At the wells there is generally a bed of clay under the surface peat or muck, but it seems to be confined to a strip only a little wider than the flowing-well district, for farther westward, at the border of the valley, a gravelly strip sets in. This gravel apparently receives the water discharged from the surface of the higher land west of the valley and conveys it to the flowing wells with hydrostatic pressure barely sufficient to cause a flow. Confirmatory evidence of the derivation of the supply from the immediate borders of the valley is found in the fact that in dry seasons the wells are weaker than in wet seasons. Wells that have remote catchment areas are not affected so promptly, if at all, by drought.

Inasmuch as the flowing-well districts of this quadrangle, together with those of other parts of the Southern Peninsula, are discussed in a special report on flowing wells (Water-Sup. and Irr. Papers Nos. 182 and 183, U. S. Geol. Survey) only brief mention will be made of them here. The principal districts are on the lake plain, one large area being at the eastern edge of the quadrangle, north of Denton, another covering 12 square miles about York, and a third comprising 2 square miles between Milan and Cone. Flowing wells in river valleys are found at the Ann Arbor waterworks, the Ypsilanti waterworks, and near Saline. Flowing wells among morainic ridges are found in and south of Ann Arbor and northeast of Pinckney. Most of the flowing wells obtain water from the basal portion of the drift, but, as already indicated, the artesian water in the area south of Ann Arbor flows at very slight depths, and some of the wells of the Ann Arbor Water Company are shallow.

Mineral waters.—All of the deep wells in the quadrangle have yielded mineral water, and the waters of two located at Ypsilanti have been used commercially. The records as to the precise horizons at which mineral water was reached in all wells are not definite, but the Berea sandstone appears to contain it and it is derived by some wells from other formations. The water at Ypsilanti is utilized on a small scale for baths and for drinking. The chemical composition of waters obtained from several of the deep wells is shown in the following table:

Analyses of mineral water.[1]

[Parts per million.]

Constituents.	Ypsilanti.				Ann Arbor.
	1.	2.	3.	4.	5.
Silica (SiO_2)	24	340	439	15	
Iron (Fe)	Trace.	Trace.	14		
Calcium (Ca)	1,160	2,167	2,316	1,610	1,346
Magnesium (Mg)	496	943	1,064	780	315
Sodium (Na)	5,734	10,714	14,556	13,576	3,001
Potassium (K)	104	295	88	236	
Carbonate radicle (CO_3)	379	589	613	496	
Sulphur (S)	86	59			
Sulphate radicle (SO_4)	3,233	3,852	3,659	1,814	1,152
Chlorine (Cl)	9,368	19,553	26,185	24,221	7,066
Bromine (Br)	53	163	180	168	
Total solids	20,636	38,679	49,114	42;916	12,880
Hydrogen sulphide (H_2S), cubic centimeters per liter	91	140	155	67	

[1] Recomputed to ionic form and parts per million at United States Geological Survey.

1. Cornwell well ("Ypsilanti Mineral Spring"). A. B. Prescott, analyst. Water drawn March 31, 1883. Temperature, 58° F. (14.5° C.). Specific gravity at 15° C., 1.0163. Reaction alkaline. Contains traces of barium (Ba), strontium (Sr), lithium (Li), phosphate radicle (PO_4), fluorine (Fl), and borate radicle (B_2O_4).

2. Moorman well, Ypsilanti Mineral Bath Co. James H. Shepard, analyst. Water drawn September 5, 1884. Well cased to 550 feet; water derived from Dundee limestone. Temperature, 14.2° C. (57.5° F.). Specific gravity, 1.0280. Reaction alkaline.

3. Moorman well, Ypsilanti Mineral Bath Co. (same well as No. 2). DeForest Ross, analyst. Water drawn September 13, 1897. Temperature, 16.5° C. (?) Specific gravity, 1.0358. Reaction alkaline. Before this sample was drawn the casing in the well was raised until its bottom was 185 feet below the surface, so as to admit the upper and stronger water, that from the Berea sandstone.

4. Atlantis well, owned by T. C. Owen, Ypsilanti. J. H. Shepard and W. F. Pett, analysts. Water drawn from a depth of about 360 feet, July 26, 1884. Temperature, 13.7° C. (56.6° F.). Specific gravity, 1.0284. Contains traces of barium (Ba), lithium (Li), phosphate radicle (PO_4), fluorine (Fl), borate radicle (B_2O_4), and organic matter.

5. Campus well, University of Michigan. E. D. Campbell, analyst. Water drawn from a depth of about 930 feet. Specific gravity, 1.094.

The waters from the wells at Ypsilanti and Ann Arbor are discussed by A. C. Lane, in a paper on lower Michigan mineral waters (Water-Sup. and Irr. Paper No. 31, U. S. Geol. Survey, 1899); and in Rept. Geol. Survey Michigan for 1901.

The wells whose waters are included in the analyses here given were drilled in the hope of obtaining a flow, but every one of them requires pumping. Other wells, as those at Milan and South Lyon, were put down with the hope of obtaining gas or oil, and these also have been failures so far as the primary aim is concerned. The failure of the wells to supply flowing water is due to the low altitude of the outcrops of the strata that form the gathering ground for the water. The artesian head in all the strata below the Pleistocene deposits throughout the greater part of the quadrangle is below the surface level. The rock formations as a whole are less favorably conditioned than the Pleistocene deposits to yield a flow.

Detailed conditions by townships.—In Putnam Township the drift is largely gravelly or loose textured, with abundance of water at moderate depths, few wells being more than 40 feet deep. However, the flowing wells in sec. 12 are about 60 feet deep, and some of the deepest wells in the village of Pinckney are of that depth. A few wells in the northwestern part of the township are sunk to a depth of about 100 feet in order to obtain water from the rock, a softer water than that derived from the glacial deposits.

In Hamburg Township wells are generally shallow, with water at 25 to 40 feet, but on the south side of the township a few have been sunk to depths of 60 to 100 feet or more, and wells east of Hamburg village are about 60 feet. Some of the deepest wells in the southern part of the township struck water at moderate depths, in sand too fine to screen, and were accordingly continued to a coarser material. A well on the Winans estate, south of Winans Lake, 158 feet in depth, which enters sandstone about 8 feet, appears to be the only well in the township that has entered rock.

In Greenoak Township a few wells have been sunk to depths of 70 or 80 feet, but the greater part of the township affords abundance of water at depths of 30 to 50 feet. The drift is largely gravelly, and, so far as known, no wells have struck rock.

In Lyon Township a prospect boring for oil at the village of South Lyon, 1300 feet or more in depth, is said to have struck a strong flow of water in gravel at about 350 feet, and to have reached rock at about 500 feet. However, no good record of this well was kept. Wells in the east part of South Lyon, on the till plain, are 30 to 40 feet deep, while those in the west part, on the gravel plain, are only 20 feet deep. Wells on the elevated tract in the southeastern part of the township are not deep, their usual depth being 30 to 40 feet. They enter gravel and sand that lies beneath a thin sheet of till.

In Novi Township wells generally obtain water at depths of 20 to 40 feet, but a few have been sunk to depths ranging from 60 to 100 feet. On the highest points, which stand 1000 to 1020 feet above tide, wells seldom reach 75 feet. The surface of the township is very largely a clayey till, but gravel or sand has been entered at moderate depths by most wells and an abundance of water has been found.

In Dexter Township the conditions are similar to those noted in Putnam Township, which borders it on the north. Not many of the high hills in either township are occupied by residences, and most of the wells are therefore either in the sags or near the foot of the slopes and are shallow. Between North Lake and West Lake a few wells sunk on ground that stands 990 to 1040 feet above sea level reach depths exceeding 100 feet, and some wells 60 to 100 feet deep have been dug along the west bluff of Huron River, but with these exceptions not many wells in this township exceed 40 feet in depth.

In Webster Township there are some places in which deep wells have been found necessary, chiefly on the highest hills, but few of them exceed 100 feet in depth. A large number of the wells are between 30 and 50 feet and perhaps still more are less than 30 feet in depth. Except along the lines of glacial drainage, where wells are entirely in gravel to the first water bed, the surface in this township is generally coated with till, which is at many places loose textured and yields water from the level of the ground-water table.

Northfield Township comprises a large amount of plain surface, both till and gravel, the wells on which obtain water at depths ranging from 15 to 40 feet. In the southern part of the township, which stands higher, a few deep wells have been sunk, yet even in this higher part many wells have obtained water at depths less than 50 feet.

In Salem Township at some places deep wells seem to be a necessity, the most notable place being in its western part, within a radius of about 2 miles east, south, and west of Worden. Several of the wells there are 100 to 200 feet deep and pass through a thick deposit of clayey till. Many of the wells in the northern half of the township are of moderate depth, most of them being between 25 and 40 feet deep. A few east of Salem are dug to depths of 50 feet or more. Nearly all except those on the gravel plains penetrate a surface sheet of clayey till.

In T. 1 S., R. 8 E., the north half of which is called Northville and the south half Plymouth, the valleys afford boiling springs and flowing wells, and the lake plain also is favorably situated for obtaining flowing wells. A group of boiling springs in the valley of Rouge River, in secs. 8 and 9, furnishes the public supply for the village of Plymouth. Many of the wells on the morainic tracts on each side of the Rouge Valley reach depths of 60 feet or more and enter beds of gravel or sand that lie beneath a clayey till. The till is a very thin deposit in the northwestern part of the township.

In Lima Township wells generally obtain water at depths of 30 to 50 feet, and so far as reported no well exceeds 100 feet in depth. The surface is generally a loose-textured till with occasional gravelly strips, and water is absorbed sufficiently to supply the wells by direct percolation from the surrounding land.

In Scio Township the surface, except on the gravel plain along Honey and Mill creeks, is largely a clayey till, more compact, as a rule, than that in Lima Township. As a consequence, wells are in some places difficult to obtain. On the high land southeast of Dexter, and also on the moraine in the southeastern part of the township, several wells have been sunk to depths of 100 to 150 feet or more. There are also a few deep wells in the moraine on the north side of Huron River. Two wells at Dexter have struck rock, one at the German Church, at a depth of 150 feet, the other at the residence of John Gallagher, at a depth of 100 feet. In each the rock surface is a little less than 800 feet above sea level, or about 40 feet below Huron River. The deep wells on the borders of Huron River have a head about 850 feet above sea level, while the head in those in the parts of the township most remote from the river, both north and south of the valley, is higher, in some wells reaching 900 feet. It is probable that the low head along the river is due to the escape of a large part of the underground water into the river valley through springs, some of which appear to boil up from deposits below the river level.

In Ann Arbor Township the conditions for obtaining water are more diverse than in any other township of the quadrangle, owing to the differences in the elevation of the different parts of its surface. The high portions of the township as a rule require wells of considerable depth, not a few being 100 feet or more. A depth of 80 to 100 feet is also found necessary on the gravel plain in and near the university campus. Most of the flowing wells in the low land in the west part of Ann Arbor are between 75 and 150 feet in depth, but several have obtained water at depths of 25 to 30 feet. Rock has been struck in four borings made by the Ann Arbor Water Company in and near Ann Arbor; also at the court-house, at the Hay & Todd underwear factory, on the ground of the Ferdon Lumber Company, and on the university campus. The altitude of the rock surface at these borings shows a variation of but 42 feet, the lowest altitude being 630 and the highest 672 feet above tide. The head in wells in the northwestern part of the township is about 900 feet above sea level, but in Ann Arbor and in the area just east of the city it is only about 800 to 830 feet. The head appears to be slightly lower in the Huron River valley than at points a mile or more back from the river. Along the border of the valley in the vicinity of Ann Arbor there are strong springs, some of which issue from the base of the gravel deposits of the campus plain and from river terraces. There are also numerous springs on the border of the low tract in the western part of the city. Some of these issue from the base of gravel deposits and others boil up from deeper beds. One spring just west of the city limits, on the north side of Liberty street, is estimated to yield over 50,000 gallons a day, and there are others nearly as strong within the city limits. In May, 1904, at a time when a neighboring shallow well showed a temperature of only 45° F., this spring had a temperature of 50.3° F. During the summer the temperature of the spring remained at about 51° while that of the well rose to 52°. This constancy in temperature may indicate that the spring boils up from a source so deep that it is uninfluenced by the accession of the surface waters which cause the variations in the temperature of the shallow well. In this connection it may be stated that the shallow flowing wells of the Ann Arbor Water Company also show a constant temperature of about 50°, nearly the same as that of the boiling spring. They may, therefore, have a similar deep-seated source.

In Superior Township most of the wells on the gravel plain in the vicinity of Dixboro obtain an abundant supply of water at depths of 30 feet or less. The depths of the wells on the moraine southeast of this gravel plain differ greatly, ranging from 20 feet up to nearly 300 feet. One on the farm of Benjamin Geer, in sec. 2, reached a depth of 284 feet and entered rock only 17 feet. Most wells along the moraine find water at depths of 30 to 40 feet in beds of gravel intercalated in the till, but at some places there is an unbroken deposit of till from the surface down to the bed rock. Conditions on the slope southeast of this moraine are very similar to those along the moraine, most of the wells there being about 30 feet deep, although a few have failed to obtain water in the drift. A boring on the Bennett farm, in sec. 28, penetrated till 300 feet and was abandoned at the base of the drift, having struck shale which seemed unlikely to furnish water. Wells on this slope and on the lake plain to the east find water that has sufficient head to rise nearly to the surface, and wells in the lowest parts of the district may flow.

In Canton Township the conditions are similar to those in the southeastern part of Superior Township, the wells showing strong hydrostatic pressure and many of them flowing. Most of the flowing wells are about 75 feet deep, but several have obtained flows at depths of only 20 to 40 feet. A well in sec. 8, on land owned by Dr. Bonsteel, of Ypsilanti, bored in 1873 to a depth of 28 feet, afforded at first a strong gushing well, with a head 8 feet above the surface. This well now has a head only 3 feet above the surface, and its flow is reduced to a weak stream with scarcely one-hundredth of its original volume. Neighboring wells in sec. 9, on the farm of James Quartell, have shown a similar loss of head and some reduction in volume. The deeper wells, which obtain their supply from near the base of the drift at about 75 feet, have shown but little loss of head or volume.

In Freedom Township driven wells are not so common as large excavated ones and water is usually obtained at depths of 25 to 50 feet. The till plain north of the moraine as well as the moraine itself is composed of loose-textured material that is readily permeable by water and well adapted to supply it rapidly to excavated wells.

In Lodi Township the greater part of the surface is morainic and the texture of the moraine is more clayey and compact than in Freedom Township, the inner or southeast slope being especially clayey. Most of the dug wells obtain water at 40 to 60 feet though some of them reach depths of 100 or more feet. The driven wells range from about 75 feet up to 250 feet and none have reached the rock. Wells on the plain in the northwest corner of the township and those on the gravel plain in its southeastern part are shallow, being only 20 to 30 feet deep.

In Pittsfield Township deep wells are confined to the prominent moraine in its northwestern part, where several have depths of 100 to 175 feet or more, and some of these wells show the remarkably high head of nearly 900 feet. In the valley-like lowlands on the southeast border of this moraine flowing wells are obtained at depths of only 20 to 30 feet. In the remainder of the township, which is a gently undulating till tract, water is easily obtained from excavated wells, though a few driven wells have been sunk in its northwestern portion, near Saline. The excavated wells, some of which reach depths of 40 to 60 feet, strike veins without strong hydrostatic pressure, their supply being derived apparently from the immediate borders. Wells driven to a depth of 75 feet, such as those near Saline, strike water which has a head nearly level with the surface, or fully 20 feet higher than in neighboring excavated wells, 50 feet in depth.

In Ypsilanti Township excavated wells in the area west of Huron River obtain water at depths of 30 to 50 feet, but many of the wells in the area east of the river obtain water at depths of only 10 to 20 feet, from the base of the deposit of sand and gravel which covers that portion of the old lake bottom. In the city of Ypsilanti the public water supply is obtained from flowing wells in the Huron River valley, most of which are only 60 to 65 feet deep. The rock in that vicinity is struck at about 100 feet, though the Moorman well penetrated 185 feet of drift. The head in the waterworks wells is only about 685 feet above sea level, or nearly 150 feet lower than in the flowing wells of Ann Arbor.

In the part of Van Buren Township embraced in this quadrangle a coating of sandy gravel yields water at depths of only 10 to 20 feet. Near Denton flowing wells are obtained at depths of 70 feet or more. These pass largely through till after traversing a few feet of surface sand. In the eastern part of the township the sand coating is insufficient to yield water, and some wells are sunk to depths of 100 feet or more, largely through till.

In Bridgewater Township wells along lines of glacial drainage are very shallow, few of them reaching depths greater than 25 or 30 feet. The remainder of the township is morainic and contains a large amount of clayey till. Excavated wells on the morainic tracts generally obtain water at depths of 40 feet or less, but at some places it has been necessary to drive wells to the rock to obtain a sufficient supply of water. In some wells the water from the rock is brackish. The gravel and sand beds incorporated in the till appear to be restricted in extent, though they occur at several levels. As a result neighboring wells may differ greatly in depth.

In Saline Township wells obtain water at moderate depths on the morainic tracts, few of them having been sunk deeper than 50 feet. Wells in the village of Saline are also but 40 to 50 feet deep, but some on the lake plain in the southeastern part of the township have been sunk to depths of 100 feet or more, and some in the extreme southeast corner overflow. The sheet of clayey till appears to be more continuous beneath the lake plain in this township than beneath the moraine, and wells must pass through this sheet in order to obtain water.

The northern part of York Township is morainic and many of the wells there obtain water at depths of 25 to 50 feet, most of them being dug. On the lake plain, which covers the remainder of the township, there are numerous tubular wells 75 to 150 feet in depth. Those in the vicinity of the Belmore beach generally overflow, but elsewhere the water lacks a few feet of reaching the surface. There are a few flowing wells in low tracts among the morainic ridges in the northwest part of the township, and it is probable that flows may be obtained along the Saline Valley south of the village of Saline.

The eastern half of Augusta Township is a sandy plain on which wells may obtain water at depths of only 10 to 15 feet, and the conditions are similar in Sumpter Township. The western half of Augusta Township is largely a clay plain in which the deep borings, as in York Township, show strong hydrostatic pressure. Possibly flowing wells may be obtained in the northwestern part of the township.

In Clinton and Tecumseh townships, which together occupy T. 5 S., R. 4 E., wells obtain water at shallow depths, not only along the broad line of glacial drainage that runs through the western part of the township but also on the bordering morainic tracts. A few tubular wells have been sunk to depths of 75 to 150 feet, and these show a head greater than that in the flowing-well district on the lake plain to the east, the head in some wells being above 800 feet.

In Macon Township, which is largely occupied by the lake plain, numerous deep test borings have been made to obtain flowing wells, but flows have been obtained only in the northeast part of the township. The depth of these flowing wells ranges from 35 feet up to about 140 feet and the head from 720 to 755 feet above tide, there being an increase from the southeast to the northwest. The borings indicate that the head is only 700 feet in the southeast corner of the township, but reaches about 800 feet in its northwest part.

Milan Township is a clay plain except along its eastern edge, near Saline River, where sand sets in. The township has been tested for flowing wells in nearly every section, but they have been found only in two strips, one near the Whittlesey beach in its northwest corner and the other just below the Arkona beach, in a strip leading from northeast to southwest across the central part of the township. The head in the former strip is 720 feet or more; that in the latter is 685 to 700 feet. From this lower strip the head increases very slightly toward the west, but not sufficiently to equal the rise in the altitude of the surface. Consequently the wells lack a few feet of overflowing. In the southeastern part of the township the head declines abruptly so that the water level is some distance below the surface in wells that have been sunk to the base of the drift. It is, therefore, a very unpromising field for flowing wells.

In London Township, except in its southwest and southeast corners and a few places on its north border, the surface sand is of sufficient depth to yield water to wells sunk to depths of 20 feet or less. In the clayey portions of the township, where deeper wells have been sunk, rock has been encountered at the moderate depths of 40 to 60 feet. If the rock struck is limestone the well ordinarily obtains water near its surface.

The northwest corner of Exeter Township is covered by sand to a sufficient depth to supply water to wells sunk 10 to 20 feet. Elsewhere in that portion of the township that lies within this quadrangle the sand is very thin and many wells have been driven into the rock, which is struck at depths of 12 to 40 feet. In the vicinity of Maybee a good supply of water is obtained at the base of the drift at depths of 12 to 22 feet.

April, 1907.