DEPARTMENT OF THE INTERIOR
FRANKLIN K. LANE, SECRETARY
UNITED STATES GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

GEOLOGIC ATLAS
OF THE
UNITED STATES

DETROIT FOLIO
WAYNE, DETROIT, GROSSE POINTE, ROMULUS, AND WYANDOTTE QUADRANGLES

MICHIGAN

BY

W. H. SHERZER

SURVEYED IN COOPERATION WITH
THE STATE OF MICHIGAN

WASHINGTON, D. C.
ENGRAVED AND PRINTED BY THE U. S. GEOLOGICAL SURVEY
GEORGE W. STOSE, EDITOR OF GEOLOGIC MAPS   S. J. KUBEL, CHIEF ENGRAVER
1917

GEOLOGIC ATLAS OF THE UNITED STATES.

The Geological Survey is making a geologic atlas of the United States, which is being issued in parts, called folios. Each folio includes topographic and geologic maps of a certain area, together with descriptive text.

THE TOPOGRAPHIC MAP.

The features represented on the topographic map are of three distinct kinds—(1) inequalities of surface, called *relief*, as plains, plateaus, valleys, hills, and mountains; (2) distribution of water, called *drainage*, as streams, lakes, and swamps; (3) the works of man, called *culture*, as roads, railroads, boundaries, villages, and cities.

Relief.—All elevations are measured from mean sea level. The heights of many points are accurately determined, and those of the most important ones are given on the map in figures. It is desirable, however, to give the elevation of all parts of the area mapped, to delineate the outline or form of all slopes, and to indicate their grade or steepness. This is done by lines each of which is drawn through points of equal elevation above mean sea level, the vertical interval represented by each space between lines being the same throughout each map. These lines are called *contour lines* or, more briefly, *contours*, and the uniform vertical distance between each two contours is called the *contour interval*. Contour lines and elevations are printed in brown. The manner in which contour lines express altitude, form, and grade is shown in figure 1.

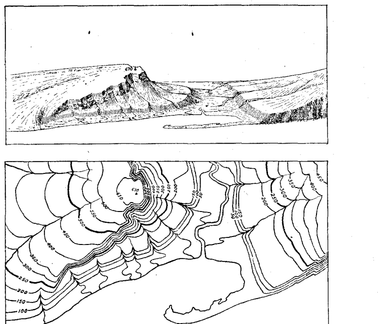


FIGURE 1.—Ideal view and corresponding contour map.

The sketch represents a river valley between two hills. In the foreground is the sea, with a bay that is partly closed by a hooked sand bar. On each side of the valley is a terrace. The terrace on the right merges into a gentle hill slope; that on the left is backed by a steep ascent to a cliff, or scarp, which contrasts with the gradual slope away from its crest. In the map each of these features is indicated, directly beneath its position in the sketch, by contour lines. The map does not include the distant portion of the view. The following notes may help to explain the use of contour lines:

1. A contour line represents a certain height above sea level. In this illustration the contour interval is 50 feet; therefore the contour lines are drawn at 50, 100, 150, and 200 feet, and so on, above mean sea level. Along the contour at 250 feet lie all points of the surface that are 250 feet above the sea—that is, this contour would be the shore line if the sea were to rise 250 feet; along the contour at 200 feet are all points that are 200 feet above the sea; and so on. In the space between any two contours are all points whose elevations are above the lower and below the higher contour. Thus the contour at 150 feet falls just below the edge of the terrace, and that at 200 feet lies above the terrace; therefore all points on the terrace are shown to be more than 150 but less than 200 feet above the sea. The summit of the higher hill is marked 670 (feet above sea level); accordingly the contour at 650 feet surrounds it. In this illustration all the contour lines are numbered, and those for 250 and 500 feet are accentuated by being made heavier. Usually it is not desirable to number all the contour lines. The accentuating and numbering of certain of them—say every fifth one—suffices and the heights of the others may be ascertained by counting up or down from these.

2. Contour lines show or express the forms of slopes. As contours are continuous horizontal lines, they wind smoothly about smooth surfaces, recede into all reentrant angles of ravines, and project in passing around spurs or prominences. These relations of contour curves and angles to forms of the landscape can be seen from the map and sketch.

3. Contour lines show the approximate grade of any slope. The vertical interval between two contours is the same, whether they lie along a cliff or on a gentle slope; but to attain a given height on a gentle slope one must go farther than on a steep slope, and therefore contours are far apart on gentle slopes and near together on steep ones.

A small contour interval is necessary to express the relief of a flat or gently undulating country; a steep or mountainous country can, as a rule, be adequately represented on the same scale by the use of a larger interval. The smallest interval used on the atlas sheets of the Geological Survey is 5 feet. This is in regions like the Mississippi Delta and the Dismal Swamp. For great mountain masses, like those in Colorado, the interval may be 250 feet and for less rugged country contour intervals of 10, 20, 25, 50, and 100 feet are used.

Drainage.—Watercourses are indicated by blue lines. For a perennial stream the line is unbroken, but for an intermittent stream it is broken or dotted. Where a stream sinks and reappears the probable underground course is shown by a broken blue line. Lakes, marshes, and other bodies of water are represented by appropriate conventional signs in blue.

Culture.—The symbols for the works of man and all lettering are printed in black.

Scales.—The area of the United States (exclusive of Alaska and island possessions) is about 3,027,000 square miles. A map of this area, drawn to the scale of 1 mile to the inch would cover 3,027,000 square inches of paper and measure about 240 by 180 feet. Each square mile of ground surface would be represented by a square inch of map surface, and a linear mile on the ground by a linear inch on the map. The scale may be expressed also by a fraction, of which the numerator is a length on the map and the denominator the corresponding length in nature expressed in the same unit. Thus, as there are 63,360 inches in a mile, the scale "1 mile to the inch" is expressed by the fraction $\frac{1}{63,360}$.

Three scales are used on the atlas sheets of the Geological Survey; they are $\frac{1}{250,000}$, $\frac{1}{125,000}$, and $\frac{1}{62,500}$, corresponding approximately to 4 miles, 2 miles, and 1 mile on the ground to an inch on the map. On the scale of $\frac{1}{62,500}$ a square inch of map surface represents about 1 square mile of earth surface; on the scale of $\frac{1}{125,000}$, about 4 square miles; and on the scale of $\frac{1}{250,000}$, about 16 square miles. At the bottom of each atlas sheet the scale is expressed in three ways—by a graduated line representing miles and parts of miles, by a similar line indicating distance in the metric system, and by a fraction.

Atlas sheets and quadrangles.—The map of the United States is being published in atlas sheets of convenient size, which represent areas bounded by parallels and meridians. These areas are called *quadrangles*. Each sheet on the scale of $\frac{1}{250,000}$ represents one square degree—that is, a degree of latitude by a degree of longitude; each sheet on the scale of $\frac{1}{125,000}$ represents one-fourth of a square degree, and each sheet on the scale of $\frac{1}{62,500}$ one-sixteenth of a square degree. The areas of the corresponding quadrangles are about 4000, 1000, and 250 square miles, though they vary with the latitude.

The atlas sheets, being only parts of one map of the United States, are not limited by political boundary lines, such as those of States, counties, and townships. Many of the maps represent areas lying in two or even three States. To each sheet, and to the quadrangle it represents, is given the name of some well-known town or natural feature within its limits, and at the sides and corners of each sheet are printed the names of adjacent quadrangles, if the maps are published.

THE GEOLOGIC MAPS.

The maps representing the geology show, by colors and conventional signs printed on the topographic base map, the distribution of rock masses on the surface of the land and, by means of structure sections, their underground relations, so far as known and in such detail as the scale permits.

KINDS OF ROCKS.

Rocks are of many kinds. On the geologic map they are distinguished as igneous, sedimentary, and metamorphic.

Igneous rocks.—Rocks that have cooled and consolidated from a state of fusion are known as *igneous*. Molten material has from time to time been forced upward in fissures or channels of various shapes and sizes through rocks of all ages to or nearly to the surface. Rocks formed by the consolidation of molten material, or magma, within these channels—that is, below the surface—are called *intrusive*. Where the intrusive rock occupies a fissure with approximately parallel walls it is called a *dike*; where it fills a large and irregular conduit the mass is termed a *stock*. Where molten magma traverses stratified rocks it may be intruded along bedding planes; such masses are called *sills* or *sheets* if comparatively thin, and *laccoliths* if they occupy larger chambers produced by the pressure of the magma. Where inclosed by rock molten material cools slowly, with the result that intrusive rocks are generally of crystalline texture. Where the channels reach the surface the molten material poured out through them is called *lava*, and lavas often build up volcanic mountains. Igneous rocks that have solidified at the surface are called *extrusive* or *effusive*. Lavas generally cool more rapidly than intrusive rocks and as a rule contain, especially in their superficial parts, more or less volcanic glass, produced by rapid chilling. The outer parts of lava flows also are usually porous, owing to the expansion of the gases originally present in the magma. Explosive action, due to these gases, often accompanies volcanic eruptions, causing ejections of dust, ash, lapilli, and larger fragments. These materials, when consolidated, constitute breccias, agglomerates, and tuffs.

Sedimentary rocks.—Rocks composed of the transported fragments or particles of older rocks that have undergone disintegration, of volcanic ejecta deposited in lakes and seas, or of materials deposited in such water bodies by chemical precipitation are termed *sedimentary*.

The chief agent in the transportation of rock débris is water in motion, including rain, streams, and the water of lakes and of the sea. The materials are in large part carried as solid particles, and the deposits are then said to be mechanical. Such are gravel, sand, and clay, which are later consolidated into conglomerate, sandstone, and shale. Some of the materials are carried in solution, and deposits of these are called organic if formed with the aid of life, or chemical if formed without the aid of life. The more important rocks of chemical and organic origin are limestone, chert, gypsum, salt, iron ore, peat, lignite, and coal. Any one of the kinds of deposit named may be separately formed, or the different materials may be intermingled in many ways, producing a great variety of rocks.

Another transporting agent is air in motion, or wind, and a third is ice in motion, or glaciers. The most characteristic of the wind-borne or eolian deposits is loess, a fine-grained earth; the most characteristic of glacial deposits is till, a heterogeneous mixture of bowlders and pebbles with clay or sand.

Sedimentary rocks are usually made up of layers or beds which can be easily separated. These layers are called *strata*, and rocks deposited in such layers are said to be stratified.

The surface of the earth is not immovable; over wide regions it very slowly rises or sinks, with reference to the sea, and shore lines are thereby changed. As a result of upward movement marine sedimentary rocks may become part of the land, and most of our land areas are in fact occupied by rocks originally deposited as sediments in the sea.

Rocks exposed at the surface of the land are acted on by air, water, ice, animals, and plants, especially the low organisms known as bacteria. They gradually disintegrate and the more soluble parts are leached out, the less soluble material being left as a *residual* layer. Water washes this material down the slopes, and it is eventually carried by rivers to the ocean or other bodies of water. Usually its journey is not continuous, but it is temporarily built into river bars and flood plains, where it forms *alluvium*. Alluvial deposits, glacial deposits (collectively known as *drift*), and eolian deposits belong to the *surficial* class, and the residual layer is commonly included with them. Their upper parts, occupied by the roots of plants, constitute soils and subsoils, the soils being usually distinguished by a notable admixture of organic matter.

Metamorphic rocks.—In the course of time, and by various processes, rocks may become greatly changed in composition and in texture. If the new characteristics are more pronounced than the old such rocks are called *metamorphic*. In the process of metamorphism the constituents of a chemical rock may enter into new combinations and certain substances may be lost or new ones added. A complete gradation from the primary to the metamorphic form may exist within a single rock mass. Such changes transform sandstone into quartzite and limestone into marble and modify other rocks in various ways.

From time to time during geologic ages rocks that have been deeply buried and have been subjected to enormous pressures, to slow movement, and to igneous intrusion have been afterward raised and later exposed by erosion. In such rocks the original structures may have been lost entirely and new ones substituted. A system of planes of division, along which the rock splits most readily, may have been developed. This structure is called *cleavage* and may cross the original bedding planes at any angle. The rocks characterized by it are *slates*. Crystals of mica or other minerals may have grown in the rock in such a way as to produce a laminated or foliated structure known as *schistosity*. The rocks characterized by this structure are *schists*.

As a rule, the oldest rocks are most altered and the younger formations have escaped metamorphism, but to this rule there are many important exceptions, especially in regions of igneous activity and complex structure.

FORMATIONS.

For purposes of geologic mapping rocks of all the kinds above described are divided into *formations*. A sedimentary formation contains between its upper and lower limits either rocks of uniform character or rocks more or less uniformly varied in character, as, for example, an alternation of shale and limestone. Where the passage from one kind of rocks to another is gradual it may be necessary to separate two contiguous formations by an arbitrary line, and in some cases the distinction depends almost entirely on the contained fossils. An igneous formation contains one or more bodies of one kind, of similar occurrence, or of like origin. A metamorphic formation may consist of rock of uniform character or of several rocks having common characteristics or origin.

When for scientific or economic reasons it is desirable to recognize and map one or more specially developed parts of a varied formation, such parts are called *members*, or by some other appropriate term, as *lentils*.

AGES OF ROCKS.

Geologic time.—The time during which rocks were made is divided into *periods*. Smaller time divisions are called *epochs*, and still smaller ones *stages*. The age of a rock is expressed by the name of the time interval in which it was formed.

The sedimentary formations deposited during a period are grouped together into a *system*. The principal divisions of a system are called *series*. Any aggregate of formations less than a series is called a *group*.

Inasmuch as sedimentary deposits accumulate successively the younger rest on those that are older, and their relative ages may be determined by observing their positions. In many regions of intense disturbance, however, the beds have been overturned by folding or superposed by faulting, so that it may be difficult to determine their relative ages from their present positions; under such conditions fossils, if present, may indicate which of two or more formations is the oldest.

Many stratified rocks contain *fossils*, the remains or imprints of plants and animals which, at the time the strata were deposited, lived in bodies of water or were washed into them, or were buried in surficial deposits on the land. Such rocks are called fossiliferous. By studying fossils it has been found that the life of each period of the earth's history was to a great extent different from that of other periods. Only the simpler kinds of marine life existed when the oldest fossiliferous rocks were deposited. From time to time more complex kinds developed, and as the simpler ones lived on in modified forms life became more varied. But during each period there lived peculiar forms, which did not exist in earlier times and have not existed since; these are *characteristic types*, and they define the age of any bed of rock in which they are found. Other types passed on from period to period, and thus linked the systems together, forming a chain of life from the time of the oldest fossiliferous rocks to the present. Where two sedimentary formations are remote from each other and it is impossible to observe their relative positions, the characteristic fossil types found in them may determine which was deposited first. Fossil remains in the strata of different areas, provinces, and continents afford the most important means for combining local histories into a general earth history.

It is many places difficult or impossible to determine the age of an igneous formation, but the relative age of such a formation can in general be ascertained by observing whether an associated sedimentary formation of known age is cut by the igneous mass or is deposited upon it. Similarly, the time at which metamorphic rocks were formed from the original masses may be shown by their relations to adjacent formations of known age; but the age recorded on the map is that of the original masses and not that of their metamorphism.

Symbols, colors, and patterns.—Each formation is shown on the map by a distinctive combination of color and pattern and is labeled by a special letter symbol.

Patterns composed of parallel straight lines are used to represent sedimentary formations deposited in the sea, in lakes, or in other bodies of standing water. Patterns of dots and circles represent alluvial, glacial, and eolian formations. Patterns of triangles and rhombs are used for igneous formations. Metamorphic rocks of unknown origin are represented by short dashes irregularly placed; if the rock is schist the dashes may be arranged in wavy lines parallel to the structure planes. Suitable combination patterns are used for metamorphic formations known to be of sedimentary or of igneous origin. The patterns of each class are printed in various colors. With the patterns of parallel lines, colors are used to indicate age, a particular color being assigned to each system.

The symbols consist each of two or more letters. If the age of a formation is known the symbol includes the system symbol, which is a capital letter or monogram; otherwise the symbols are composed of small letters.

The names of the systems and of series that have been given distinctive names, in order from youngest to oldest, with the color and symbol assigned to each system, are given in the subjoined table.

Symbols and colors assigned to the rock systems.

	System.	Series.	Symbol.	Color for sedimentary rocks.
Cenozoic	Quaternary	Recent Pleistocene	Q	Brownish yellow.
	Tertiary	Pliocene Miocene Oligocene Eocene	T	Yellow ocher.
Mesozoic	Cretaceous		K	Olive-green.
	Jurassic		J	Blue-green.
	Triassic		TR	Peacock-blue.
Paleozoic	Carboniferous	Permian Pennsylvanian Mississippian	C	Blue.
	Devonian		D	Blue-gray.
	Silurian		S	Blue-purple.
	Ordovician		O	Red-purple.
	Cambrian		Є	Brick-red.
	Algonkian		A	Brownish red.
	Archean		AR	Gray-brown.

SURFACE FORMS.

Hills, valleys, and all other surface forms have been produced by geologic processes. For example, most valleys are the result of erosion by the streams that flow through them (see fig. 1), and the alluvial plains bordering many streams were built up by the streams; waves cut sea cliffs and, in cooperation with currents, build up sand spits and bars. Topographic forms thus constitute part of the record of the history of the earth.

Some forms are inseparably connected with deposition. The hooked spit shown in figure 1 is an illustration. To this class belong beaches, alluvial plains, lava streams, drumlins (smooth oval hills composed of till), and moraines (ridges of drift made at the edges of glaciers). Other forms are produced by erosion. The sea cliff is an illustration; it may be carved from any rock. To this class belong abandoned river channels, glacial furrows, and peneplains. In the making of a stream terrace an alluvial plain is first built and afterward partly eroded away. The shaping of a marine or lacustrine plain is usually a double process, hills being worn away (*degraded*) and valleys being filled up (*aggraded*).

All parts of the land surface are subject to the action of air, water, and ice, which slowly wear them down, and streams carry the waste material to the sea. As the process depends on the flow of water to the sea, it can not be carried below sea level, and the sea is therefore called the *base-level* of erosion. Lakes or large rivers may determine local base-levels for certain regions. When a large tract is for a long time undisturbed by uplift or subsidence it is degraded nearly to base-level, and the fairly even surface thus produced is called a *peneplain*. If the tract is afterward uplifted, the elevated peneplain becomes a record of the former close relation of the tract to base-level.

THE VARIOUS GEOLOGIC SHEETS.

Areal geology map.—The map showing the areas occupied by the various formations is called an *areal geology map*. On the margin is a *legend*, which is the key to the map. To ascertain the meaning of any color or pattern and its letter symbol the reader should look for that color, pattern, and symbol in the legend, where he will find the name and description of the formation. If it is desired to find any particular formation, its name should be sought in the legend and its color and pattern noted; then the areas on the map corresponding in color and pattern may be traced out. The legend is also a partial statement of the geologic history. In it the names of formations are arranged in columnar form, grouped primarily according to origin—sedimentary, igneous, and crystalline of unknown origin—and within each group they are placed in the order of age, so far as known, the youngest at the top.

Economic geology map.—The map representing the distribution of useful minerals and rocks and showing their relations to the topographic features and to the geologic formations is termed the *economic geology map*. The formations that appear on the areal geology map are usually shown on this map by fainter color patterns and the areas of productive formations are emphasized by strong colors. A mine symbol shows the location of each mine or quarry and is accompanied by the name of the principal mineral mined or stone quarried. If there are important mining industries or artesian basins in the area special maps to show these additional economic features are included in the folio.

Structure-section sheet.—In cliffs, canyons, shafts, and other natural and artificial cuttings the relations of different beds to one another may be seen. Any cutting that exhibits those relations is called a *section*, and the same term is applied to a diagram representing the relations. The arrangement of rocks in the earth is the earth's *structure*, and a section exhibiting this arrangement is called a *structure section*.

The geologist is not limited, however, to natural and artificial cuttings for his information concerning the earth's structure. Knowing the manner of formation of rocks and having traced out the relations among the beds on the surface, he can infer their relative positions after they pass beneath the surface and can draw sections representing the structure to a considerable depth. Such a section is illustrated in figure 2.

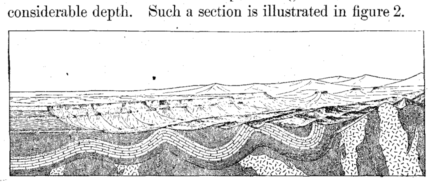


FIGURE 2.—Sketch showing a vertical section at the front and a landscape beyond.

The figure represents a landscape which is cut off sharply in the foreground on a vertical plane, so as to show the underground relations of the rocks. The kinds of rock are indicated by appropriate patterns of lines, dots, and dashes. These patterns admit of much variation, but those shown in figure 3 are used to represent the commoner kinds of rock.

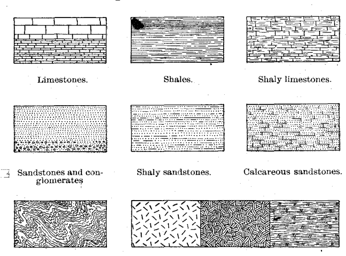


FIGURE 3.—Symbols used in sections to represent different kinds of rocks.

The plateau shown at the left of figure 2 presents toward the lower land an escarpment, or front, which is made up of sandstones, forming the cliffs, and shales, constituting the slopes. The broad belt of lower land is traversed by several ridges, which are seen in the section to correspond to the outcrops of a bed of sandstone that rises to the surface. The upturned edges of this bed form the ridges, and the intermediate valleys follow the outcrops of limestone and calcareous shale.

Where the edges of the strata appear at the surface their thickness can be measured and the angles at which they dip below the surface can be observed. Thus their positions underground can be inferred. The direction of the intersection of a bed with a horizontal plane is called the *strike*. The inclination of the bed to the horizontal plane, measured at right angles to the strike, is called the *dip*.

In many regions the strata are bent into troughs and arches, such as are seen in figure 2. The arches are called *anticlines* and the troughs *synclines*. As the sandstones, shales, and limestones were deposited beneath the sea in nearly flat sheets, the fact that they are now bent and folded is proof that forces have from time to time caused the earth's surface to wrinkle along certain zones. In places the strata are broken across and the parts have slipped past each other. Such breaks are termed *faults*. Two kinds of faults are shown in figure 4.

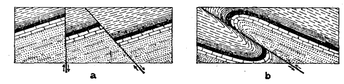


FIGURE 4.—Ideal sections of strata, showing (a) *normal* faults and (b) a *thrust* or *reverse* fault.

At the right of figure 2 the section shows schists that are traversed by igneous rocks. The schists are much contorted and their arrangement underground can not be inferred. Hence that portion of the section delineates what is probably true but is not known by observation or by well-founded inference.

The section also shows three sets of formations, distinguished by their underground relations. The uppermost set, seen at the left, is made up of sandstones and shales, which lie in a horizontal position. These strata were laid down under water but are now high above the sea, forming a plateau, and their change of elevation shows that a portion of the earth's mass has been uplifted. The strata of this set are parallel, a relation which is called *conformable*.

The second set of formations consists of strata that have been folded into arches and troughs. These strata were once continuous, but the crests of the arches have been removed by erosion. The beds, like those of the first set, are conformable.

The horizontal strata of the plateau rest upon the upturned, eroded edges of the beds of the second set shown at the left of the section. The overlying deposits are, from their position, evidently younger than the underlying deposits, and the bending and eroding of the older beds must have occurred between their deposition and the accumulation of the younger beds. The younger rocks are *unconformable* to the older, and the surface of contact is an *unconformity*.

The third set of formations consists of crystalline schists and igneous rocks. At some period of their history the schists were folded or plicated by pressure and traversed by eruptions of molten rock. But the pressure and intrusion of igneous rocks have not affected the overlying strata of the second set. Thus it is evident that a considerable interval elapsed between the formation of the schists and the beginning of deposition of the strata of the second set. During this interval the schists were metamorphosed, they were disturbed by eruptive activity, and they were deeply eroded. The contact between the second and third sets is another unconformity; it marks a time interval between two periods of rock formation.

The section and landscape in figure 2 are ideal, but they illustrate actual relations. The sections on the structure-section sheet are related to the maps as the section in the figure is related to the landscape. The profile of the surface in the section corresponds to the actual slopes of the ground along the section line, and the depth from the surface of any mineral-producing or water-bearing stratum that appears in the section may be measured by using the scale of the map.

Columnar section.—The geologic maps are usually accompanied by a *columnar section*, which contains a concise description of the sedimentary formations that occur in the quadrangle. It presents a summary of the facts relating to the character of the rocks, the thickness of the formations, and the order of accumulation of successive deposits.

The rocks are briefly described, and their characters are indicated in the columnar diagram. The thicknesses of formations are given in figures that state the least and greatest measurements, and the average thickness of each formation is shown in the column, which is drawn to scale. The order of accumulation of the sediments is shown in the columnar arrangement—the oldest being at the bottom, the youngest at the top.

The intervals of time that correspond to events of uplift and degradation and constitute interruptions of deposition are indicated graphically and by the word "unconformity."

GEORGE OTIS SMITH,
Director.

May, 1909.

DESCRIPTION OF THE DETROIT DISTRICT.

By W. H. Sherzer.[1]

INTRODUCTION.

GENERAL RELATIONS.

The area mapped and described in this folio and here called the Detroit district lies between parallels 42° and 42° 30′ and extends westward from Lake St. Clair, Detroit River, and Lake Erie to meridian 83° 30′. It comprises the Wayne, Detroit, Grosse Pointe, Romulus, and Wyandotte quadrangles and includes a land area of 772 square miles. It is in southeastern Michigan and includes the greater part of Wayne County and small parts of Macomb, Monroe, and Oakland counties. The city of Detroit is in the northeastern part of the district. (See fig. 1.)

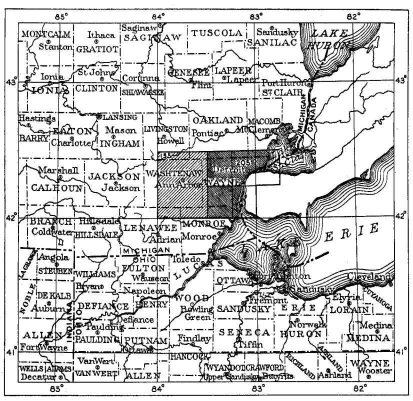


FIGURE 1.—Index map of southeastern Michigan and parts of adjacent States.

The district described in the Detroit folio (No. 205) is indicated by the darker ruling. The lighter ruling shows the area described in the Ann Arbor folio (No. 155).

In its general geographic and geologic relations the district forms a part of the Glaciated Plains, which lie between the Laurentian Upland on the north, the Appalachian province on the east and southeast, the Ozark province on the southwest and the Great Plains on the west. The Glaciated Plains and Appalachian province merge into each other in a border zone where the minor topographic features are due to glaciation but where the drift sheet is not so thick as to conceal the larger relief of the bedrock surface. For convenience the boundary between the two provinces across Indiana and Ohio is placed along the southern limit of the area invaded by the Pleistocene ice sheets.

GENERAL GEOGRAPHY AND GEOLOGY OF THE CENTRAL GREAT LAKES REGION.

Interest and importance.—The central Great Lakes region, the part of the Glaciated Plains in the heart of which the Detroit district is situated (see fig. 2), includes Lakes Michigan, Huron, and Erie and their drainage basins. Northern and central Indiana, central Ohio, and northwestern Pennsylvania, although lying in the drainage basin of the Mississippi, are closely associated with the rest of the central Great Lakes region in their geologic history and their commercial relations and are regarded as parts of it.

Although marked by relatively simple rock structure the region is one of interesting geologic relations and has had a complicated and fascinating history, especially in Quaternary time. The resulting geographic conditions are of great importance from the human point of view and have made the region one of the most densely settled and commercially important parts of North America. Chicago and Milwaukee lie on its western, Cincinnati on its southern, and Pittsburgh and Buffalo on its eastern border, and within it are Cleveland, Detroit, Indianapolis, and Columbus. The largest waterborne commerce of the world is that carried by the central Great Lakes and Detroit River, and the region is crossed by the trunk-line railroads that connect Chicago and the upper Mississippi basin with the Atlantic seaboard and most of which run along or near Lake Erie. The facilities for cheap water transportation of raw materials like ore and lumber and the proximity of great coal fields on the south have made the region a manufacturing territory of the first importance.

[1] Prepared in cooperation with the State Geological Survey of Michigan. The introduction was prepared mainly by Laurence LaForge, of the U. S. Geological Survey.

The Detroit district, as will be shown later, occupies a sort of focal position in the region—geologically, geographically, and commercially. This advantage of position, a favorable climate, and abundant natural resources of several sorts in the immediate neighborhood have combined to cause the rapid development of the city as a commercial and manufacturing center.

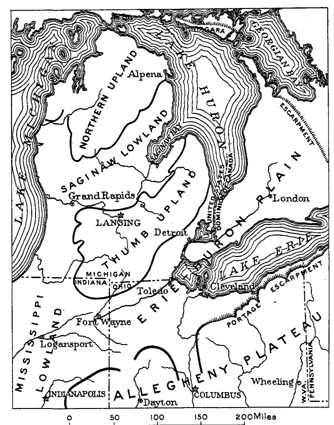


FIGURE 2.—Map showing the topographic divisions of the central Great Lakes region.

The Allegheny Plateau lies chiefly in the Appalachian province, the southeastern boundary of the Glaciated Plains (not shown on the map) being an irregular diagonal line which crosses central Ohio to northwestern Pennsylvania.

Divisions.—The topographic divisions lying wholly or partly in the central Great Lakes region are the Lower Peninsula of Michigan, the Erie-Huron Plain, the Mississippi Lowland, and the Allegheny Plateau. The Lower Peninsula of Michigan constitutes a topographic subprovince by itself, comprising three minor parts—the Northern Upland, the Saginaw Lowland, and the Thumb Upland. (See fig. 2.) The Northern Upland, as its name implies, occupies most of the northern part of the peninsula; the Saginaw Lowland extends from Saginaw and Thunder bays southwestward across the peninsula and along the shore of Lake Michigan; and the Thumb Upland, named from the land projection east of Saginaw Bay (the "thumb" of the "mitten" to which the Lower Peninsula has been compared in shape), occupies most of the southern part and extends a short distance into Ohio and Indiana.

The southeast corner of Michigan, northwestern Ohio, and the peninsula of Ontario are occupied by the Erie-Huron Plain, which also forms the bed of Lake Erie, as the lake is shallow and lies in a low part of the plain itself rather than in a deep valley therein. In New York the Erie Plain lies 100 feet or more higher than the Huron Plain, from which it is separated by the Onondaga escarpment, but in Ontario the escarpment is low and obscured by drift and the two plains are virtually one, which extends northwestward to form part of the bed of Lake Huron and laps around the north end of the peninsula into the basin of Lake Michigan. On the northeast it is bounded by the Niagara escarpment, which faces toward the Ontario Lowland. Southwestward the plain extends into Indiana and merges into the Mississippi Lowland, which also extends to the basin of Lake Michigan. The uplands of the Lower Peninsula are thus surrounded by plains partly covered by lakes.

Southeast of the plains is the Allegheny Plateau, which occupies about two-thirds of Ohio and extends westward into Indiana, southward into Kentucky and West Virginia, and northeastward across Pennsylvania into New York. It lies chiefly in the Appalachian province, as the margin of the drift-covered area, which forms the boundary between the Glaciated Plains and Appalachian provinces, is an irregular line that crosses the plateau from southern Indiana and northern Kentucky to northwestern Pennsylvania. In New York and Pennsylvania the plateau is bounded on the north by the Portage escarpment and stands from 800 to 1,500 feet above the Erie Plain, but in Ohio the escarpment is lower and less steep and is broken by broad embayments. It decreases in height southwestward and in western Ohio and eastern Indiana, where the bedrock topography is much obscured by a thick mantle of drift, it becomes a broad, gentle slope that rises 300 to 400 feet in 20 miles.

Relief.—The altitude of Lake Erie is 573 feet and that of Lakes Huron and Michigan 582 feet above sea level, and the land surface of the region ranges in altitude from that of the lake shores to 1,700 feet in the Northern Upland and on the Allegheny Plateau. Lake Erie is nowhere more than 150 feet deep, but the greatest depth of Lake Huron is more than 700 feet and that of Lake Michigan nearly 900 feet, so that parts of the bottoms of both those lakes are below sea level and the total relief of the region is 2,000 feet or more.

The general altitude of the Northern Upland is 1,100 to 1,300 feet above sea level, rising to 1,700 feet near Cadillac. There is generally a rather abrupt descent about the border of the upland to 800 feet and around the north end of the peninsula the margin of the upland is indented by valleys and lowlands that lie below 800 feet. The Saginaw Lowland lies in general from 600 to 800 feet above sea level, but it is crossed by morainic ridges which in places reach an altitude of 1,000 feet. The Thumb Upland has a general altitude of 900 to 1,000 feet but reaches 1,300 feet at points in Oakland and Hillsdale counties.

The upland border of the Erie-Huron Plain lies in general between 800 and 900 feet above sea level and the plain slopes from that altitude to the shores of the lakes. Its surface is smooth or broadly rolling and is broken here and there by low morainic accumulations and by the beach ridges of former lakes. Southwestward the plain merges, at an altitude of about 800 feet, into the Mississippi Lowland, which, in Indiana, ranges between 700 and 900 feet above sea level and descends gently northward to Lake Michigan and southwestward to central Illinois.

The general surface of the Allegheny Plateau lies between 900 and 1,100 feet above sea level in eastern Indiana and western and southern Ohio and between 1,100 and 1,300 feet, with here and there hills rising to 1,400 feet, in eastern and northeastern Ohio. Its culminating point in Indiana, in Randolph County, stands a little above 1,200 feet, and in Ohio two hills in Richland County and one in Logan County stand above 1,500 feet, the hill in Logan County being the highest point in the State. In northwestern Pennsylvania the surface rises eastward and northeastward, at first gently and then more abruptly, and reaches 1,800 feet above sea level at the western boundary of New York.

The surface of the plateau in Indiana and in western, central, and northeastern Ohio is broadly rolling and is dissected by wide and rather shallow valleys with gently sloping sides. In southern and southeastern Ohio the country, though in general no higher, is much rougher and the surface is rather closely dissected by steep-sided valleys, the largest of which are 400 to 500 feet deep and have flat bottoms of some width. This difference in topography is due largely to the character of the underlying rocks, but it is also due in part to a difference in the drainage history, in part to the fact that one region has been glaciated and the other has not, and perhaps in part to a slight southeasterly tilt of the land surface.

Bedrock surface.—In the Allegheny Plateau the altitude, relief, and larger topographic features of the present surface are due chiefly to the form of the bedrock surface and in only a few areas is the drift thick enough to conceal the bedrock topography. The Erie-Huron Plain, however, owes much of its smoothness and the present altitude of its surface to the drift mantle, which is not very thick near the lakes but which increases in thickness southwestward and in parts of the Mississippi Lowland in northern Indiana is several hundred feet thick. The present surface of northern Indiana is formed entirely of drift and is but slightly affected by the form of the bedrock surface, of which only the broader features are known. The slope bounding the Allegheny Plateau owes its position and height to the underlying rock, however, and if the mantle of drift in the lowland were removed the plain and plateau would be as distinctly separated and the escarpment would be nearly as high and bold in central Indiana as in northeastern Ohio.

The general altitude of the Thumb Upland is due to the resistant Marshall sandstone. Beneath the drift the bedrock surface of the upland is in general high and is highest where the present surface is highest. (See fig. 3.) The Saginaw Lowland occupies a depression in the bedrock surface, which rises again beneath the Northern Upland to about the same altitude as beneath the Thumb Upland. There is thus a rude correspondence between the form of the present surface of the

Lower Peninsula and that of the bedrock surface. The bedrock surface is covered, however, with a heavy mantle of drift, which in the northern part of the peninsula reaches a thickness

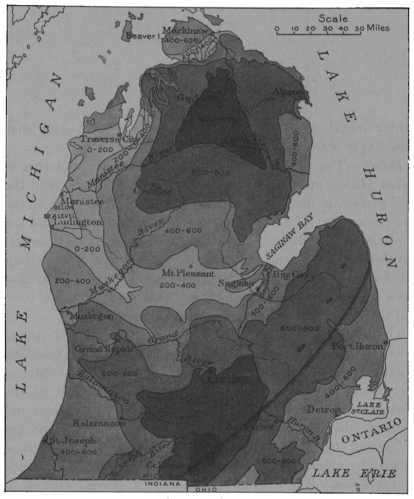


Figure 3.—Relief map of the bedrock surface of the Southern Peninsula of Michigan.

Elevation above sea level is shown by different shading for vertical intervals of 200 feet. The lakes are about 580 feet above sea level. The hachured line in the southeastern part of the peninsula represents the crest of a rock cuesta which slopes gently northwestward.

of 1,000 feet, and it not only lies far below the present surface, but beneath about half the area of the peninsula it lies below the level of the lakes. (See fig. 3.) Indeed, the bedrock surface of a considerable area in the northwestern part of the peninsula lies nearly 600 feet below the lake level and a small part of it is actually below sea level.

These low areas of the bedrock surface of the peninsula, as well as much of the bottoms of Lakes Michigan and Huron, at present lie too low to be drained to the sea. It is probable, therefore, that they are now lower than they were in preglacial time, but it can not yet be determined whether they have been carried down by warping or by general subsidence or have been scoured to a great depth by glacial erosion, although both causes seem likely to have been operative.

Drainage.—The region lies partly in the drainage basin of the St. Lawrence and partly in that of the Mississippi. The Lower Peninsula of Michigan, the Erie-Huron Plain, and a small part of the Allegheny Plateau in northeastern Ohio and northwestern Pennsylvania are drained through the Great Lakes to the St. Lawrence. The rest of the Allegheny Plateau within the region and the part of the Mississippi Lowland in Indiana are drained to the Mississippi, chiefly by way of Ohio River but partly through Kankakee and Illinois rivers. The divide between the two great drainage basins lies near the northern margin of the Allegheny Plateau in northwestern Pennsylvania and in northeastern and north-central Ohio. In western Ohio it turns northwestward and extends across Indiana nearly to Lake Michigan between the tributaries of Maumee and St. Joseph rivers on one side and those of Wabash and Kankakee rivers on the other. Thence it turns southwestward again parallel to and not far from the lake shore. For much of its length it traverses nearly flat country and is scarcely perceptible.

The part of Ohio south of the divide and the part of Indiana south of the latitude of Fort Wayne are well drained, except at the extreme headwaters of the streams, and contain few swamps and almost no lakes. In northern Indiana and the Lower Peninsula of Michigan the streams are postglacial, the drainage is still youthful and obstructed, and swamps and small lakes abound. The Erie Plain in northwestern Ohio and southeastern Michigan is much better drained, but the streams are still youthful, much of the country was swampy before it was settled and artificially drained, and a few small lakes are scattered about.

Stratigraphy.—The indurated rocks of the region, exclusive of the area north of Georgian Bay, which will not be here considered, are wholly stratified rocks of Paleozoic age ranging from early Ordovician to Pennsylvanian. (See fig. 4.) The strata consist chiefly of limestone, dolomite, shale, and sandstone, but they include also some conglomerate, as well as thick beds of rock salt, gypsum, and coal. The rocks have been comparatively little disturbed or altered from their original character. Many beds are richly fossiliferous.

The upper part of the Ordovician system is represented by 600 to 700 feet of limestone and shale. These rocks occupy an area in southwestern Ohio and southeastern Indiana and a belt along the northeast side of the peninsula and islands between Georgian Bay and Lake Huron. The same belt turns southward west of Lake Michigan, and a little of it is shown in the upper left corner of figure 4. The Ordovician strata probably underlie all the rest of the region except northeast of Georgian Bay and they have been penetrated in several places by borings.

The Silurian system is rather fully represented by 200 to 1,000 feet or more of shale, limestone, dolomite, rock salt, and gypsum. The rocks occupy a large area in eastern Indiana, western Ohio, and about the west end of Lake Erie, and a belt extending across the Ontario peninsula, along the north side of Lake Huron, around the north end of the Lower Peninsula of Michigan, and along the west side of Lake Michigan. They also probably underlie all the rest of the region except the area north of Georgian Bay and those where Ordovician rocks occupy the surface.

Although strata of Devonian age are more widely distributed in the region than those of other ages, the system is not fully represented, as Lower Devonian beds are almost wholly absent and the Upper Devonian series is not well developed. Several formations are found in only part of the region and the whole assemblage of beds thins very greatly to the west and south. The strata consist chiefly of limestone and shale but include some sandstone. They occupy the western part of the Ontario peninsula and both sides of Lake Erie except at its west end. From this central area, where their thickness is about 1,700 feet, a narrow belt extends southward across Ohio, another, somewhat wider, extends southwestward past Detroit and across northern Indiana to Lake Michigan, and a third extends northwestward beneath Lake Huron and reappears about the north end of the Lower Peninsula. It continues southward beneath Lake Michigan to join the second belt, and thus the Lower Peninsula is surrounded by a belt of Devonian strata. A fourth belt crosses Indiana from northwest to southeast.

Strata of Carboniferous age, comprising the Mississippian, Pennsylvanian, and Permian series, occupy more of the region than those of any other system. (See fig. 4.) They consist of shale, sandstone, some conglomerate and limestone, and many

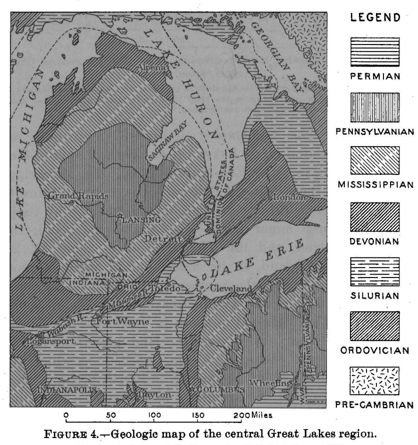


Figure 4.—Geologic map of the central Great Lakes region.
From geologic map of North America, U. S. Geol. Survey, 1911.

beds of coal. All three series are represented. Mississippian strata, chiefly shale, sandstone, and limestone, 900 to 1,600 feet thick, occupy a belt extending westward across northeastern Ohio and thence southward across central Ohio, a broad ring surrounding the central part of the Lower Peninsula of Michigan and occupying about half the area of the peninsula, and a belt in west-central Indiana. Pennsylvanian strata, in which the most abundant and thickest coal beds are found, occupy eastern Ohio and extend southwestward toward Kentucky, and also occupy the central area of the Lower Peninsula of Michigan. In Ohio the Pennsylvanian series is nearly 1,000 feet thick, in Michigan about 700 feet. The lower part of the Permian series, consisting of 500 feet or more of shale and sandstone with some beds of coal and of limestone, occupies an area in southeastern Ohio, southwestern Pennsylvania, and northern West Virginia.

Throughout nearly the whole region the indurated rocks are covered by a thick blanket of unconsolidated deposits of Quaternary age, chiefly of glacial origin or derivation, which in places is hundreds of feet thick. These deposits consist chiefly of till and glacial outwash, but they also include much alluvium in the valleys of the larger streams and extensive lacustrine deposits about the shores of the Great Lakes and in other places.

Structure.—The strata were originally deposited in a nearly level position and have been but slightly disturbed since. However, as they were laid down in more or less basin-like areas they probably had at least some original dip of deposition, and they have since been gently warped in such a manner as nearly everywhere to accentuate that dip. Accordingly the region now displays broad and subdued but nevertheless definite structural features. These are the Michigan basin, the Pittsburgh basin, and the Cincinnati arch with its prolongations toward the northeast and northwest.

The Michigan basin or syncline, the most prominent of these features, occupies the whole of the Lower Peninsula, with some of northwestern Ohio and northern Indiana and parts of the beds of Lakes Michigan and Huron. The center and structurally the lowest part of the basin is in the center of the peninsula, toward which the strata dip from all sides. The formations are arranged like a nest of wooden butter bowls, concave side up, with the youngest and smallest occupying the surface at the center of the basin and successively older formations emerging from beneath about the margin and outcropping in concentric zones about the central area.

The southeastern part of the region shown in figure 4 is a part of the Pittsburgh basin or syncline, a similar but less regular synclinal basin whose center is not far from the southwest corner of Pennsylvania. The arrangement of the strata therein is similar to that of the Michigan basin, except that a greater thickness of strata is involved and younger beds occupy the center of the basin. In western Pennsylvania and eastern and central Ohio the beds dip southward, southeastward, and eastward toward the center of the basin and in a direction opposite to those of northwestern Ohio and southeastern Michigan.

In western Indiana the beds dip southwestward toward a third synclinal basin, that of central Illinois, of which only a part of the northeastern flank is included in the area shown in figure 4.

Between the Pittsburgh and Illinois basins lies the Cincinnati arch or anticline, a broad, roughly oval dome. The oldest and stratigraphically lowest strata are exposed at the center or structurally highest part of the fold, from which the beds dip outward in all directions, and successively younger and overlapping formations outcrop in concentric zones about the central area. The strata west of the Cincinnati arch dip west toward the Illinois basin, those north of it dip north toward the Michigan basin, and those east of it dip east toward the Pittsburgh basin. Only its northern part is included in the region shown in figure 4. The southern end of the main arch is in central Kentucky, beyond which area a broad, low, anticlinal swell extends southwestward into Alabama.

At its north end the Cincinnati arch divides into two anticlinal swells, one of which extends northwestward across Indiana to the neighborhood of Chicago as a broad, low, anticlinal cross fold which separates the Illinois and Michigan basins and connects the Cincinnati anticline with that extending from northern Wisconsin southward into Illinois. The other and more important branch extends northeastward across the west end of Lake Erie and into Ontario as a similar broad, low, anticlinal belt which separates the Michigan and Pittsburgh basins and connects the Cincinnati anticline with the pre-Cambrian area of east-central Ontario.

The region immediately about Detroit, including Lake St. Clair and the southwest end of the Ontario Peninsula, is situated nearly where this anticlinal swell is crossed by a line joining the centers of the Michigan and Pittsburgh basins, or, in other words, in a "saddle" at the lowest part of the anticlinal axis. This peculiar position and the consequent relation of the district to several of the broad structural features of the general region have had a marked effect on the geologic history and physiographic development of the district.

Outline history.—The decipherable history of the region begins in the Paleozoic era, as all record of the long and perhaps complicated series of events of pre-Cambrian time has been destroyed or is buried beneath the Paleozoic strata. In a great part of the region the record of early Paleozoic time also is so deeply buried that the strata deposited then have been penetrated only in a few widely separated deep borings, and much of the history of that time has to be inferred from the record exposed in adjoining regions. That part of the history of this region of which the record is still legible comprises three general periods, during each of which conditions in the region were strikingly different. The first, which lasted until near the close of the Paleozoic era and probably was several times as long as the other two together, was characterized chiefly by marine sedimentation. The second, which lasted throughout the Mesozoic era and the Tertiary period of the Cenozoic era, was a time of subaerial denudation of a continental land mass. The third and shortest, lasting only through the Pleistocene epoch of the Quaternary period, was a time of glaciation. As it closed but recently, geologically speaking, its record is comparatively fresh and legible and its share in the development of the topographic form and physical conditions of the region is much more obvious, especially in matters of local detail, than those of the previous ages. As will be shown later, however, the events of the Paleozoic era have had a controlling effect on all the subsequent history of the region and therefore were the principal factors in the development of the present conditions.

During the early part of the Cambrian period the region was presumably land which was being worn down by erosion to near sea level. This land was a part of the ancient continent of Laurentia, which occupied nearly all of eastern Canada and some of the northern United States. It was separated by the Appalachian Strait from the continent of Appalachia, which occupied the southeastern United States and extended for an unknown distance eastward and southward. The southwestern part of Laurentia gradually subsided and in Upper Cambrian time the interior Paleozoic sea spread widely over the region. The earth's crust was constantly undergoing slow warping and the relative level of sea and land and the position of the shore were constantly changing, but probably the sea was never quite absent and marine deposition was going on somewhere in the region until well into Permian time. During much of the Paleozoic era a great part of the region was submerged and thus, in course of time, the several thousand feet of strata now found in the region were accumulated. At times, especially early in the Devonian period and again at the beginning of the Pennsylvanian epoch, the land rose so that the sea withdrew from nearly all, perhaps all, the region and land conditions prevailed generally for a time. At other times deposition was confined largely to the main basins and the rest of the region was land. This may have been the case late in Devonian time and probably was the case in mid-Mississippian time.

By the beginning of the Silurian period, if not earlier, the main structural features were already outlined. The Cincinnati arch had begun to rise and formed an island, which probably was never again completely submerged and which several times became a peninsula joined to Laurentia. The Pittsburgh and Michigan basins also began to develop at an early date. At length, near the close of the Paleozoic era, the region, in common with a large part of eastern North America, was greatly elevated—certainly many hundred, perhaps several thousand feet—the sea withdrew finally from the whole region and marine deposition ceased. In a large part of the Appalachian province the elevation was accompanied by great deformation of the rocks and extreme metamorphism of some of them. In the central Great Lakes region, however, the deformation seems to have been confined almost wholly to warping, which generally somewhat accentuated the structural features previously outlined, and was unaccompanied by metamorphism.

The net result of the fluctuations of the Paleozoic sea and in the conditions of sedimentation was that the strata deposited in it are not uniform in lithologic character but differ from place to place and from one formation to another. Moreover, the formations were not uniformly deposited throughout the region but are more or less local in their distribution, are of irregular thickness, and different ones thin out in different directions. All these factors, as well as the broad geologic structure of the region, have had an influence on its subsequent history and the development of the present topography.

During the Mesozoic era the region was undergoing denudation by the weather and by streams. Alluvial deposits were undoubtedly formed and later cut away, but at no time, so far as any record remains, was the region submerged by standing water. Only the general outlines of the history of this time are known, however. The surface of the originally higher parts of the region was lowered hundreds of feet by denudation and at length practically the whole region was reduced to a nearly featureless plain lying near sea level. Such reduction, followed by renewed uplift and dissection of the uplifted plain, probably occurred more than once during the long time included in the Mesozoic era, but that the surface was at least once so reduced, toward the close of the era, is fairly certain. The highest parts of the bedrock surface in the Lower Peninsula, both in the Northern Upland and in the Thumb Upland, and the general upland bedrock surface of the Allegheny Plateau in Indiana and western and southern Ohio are regarded as remnants of this old, nearly base-leveled surface, or peneplain which is tentatively correlated with the Highland rim peneplain of Tennessee. Here and there small areas, either along the main divides or underlain by more resistant rocks, remained standing somewhat above the general level, and a large part of central and northeastern Ohio also seems not to have been reduced so low as the rest of the region.

Near the beginning of the Cenozoic era the region was again uplifted several hundred feet and active denudation was resumed. The uplifted peneplain was extensively dissected by the revived drainage and the parts now remaining as plateau and uplands were deeply trenched by the new valleys. This erosion cycle lasted until a considerable part of the surface was reduced nearly to the new base-level and formed a partly developed peneplain, now represented by the bedrock surface of the Erie-Huron Plain and probably of at least part of the Mississippi Lowland. In the formation of the older peneplain the erosion cycle had been so long that the rock structures had been beveled, and resistant and weak beds alike had been planed down to a nearly uniform surface, across which the trunk streams flowed in courses that were mainly independent of the rock structure.

In the new cycle the areas underlain by the less resistant beds, which are in general those of Ordovician, upper Silurian, and Devonian age, were soon reduced nearly to the new base-level. On the other hand, those underlain by the more resistant beds, in general those of middle Silurian, Mississippian, and in the Allegheny Plateau also of basal Pennsylvanian age, were little reduced, though much dissected. When this cycle in turn was closed by uplift such areas formed residual plateaus and uplands. The younger peneplain was developed, therefore, chiefly in areas where the surface was occupied by Upper Silurian and Devonian rocks, and the areas where those rocks were protected by a capping of more resistant Mississippian formations remain as dissected residual areas of the older peneplain. The broad reentrants in the northwest margin of the Allegheny Plateau are opened out on belts of the less resistant formations that extend southward along the flanks of the Cincinnati arch and so were exposed on the surface of the old peneplain.

As the streams sank their valleys into the uplifted older plain the main streams cut down so rapidly that they held their courses across the rock structure and thus deeply notched the escarpments that were being formed along the margins of the more resistant formations. One such stream seems to to have flowed directly across the Michigan basin, apparently from east to west, before the uplift. When it again began to deepen its valley it breached the ring of Mississippian strata about the basin and began to open out a lowland on the less resistant Pennsylvanian beds in the center of the basin, the beginning of the Saginaw Lowland. Thus was outlined the present form of the bedrock surface of the Lower Peninsula—uplands on resistant Mississippian rocks in the north and south, separated by a broad valley cut largely in Pennsylvanian strata, and the whole surrounded by a belt of plains opened out on Devonian and upper Silurian beds.

The younger erosion cycle was at length terminated by renewed uplift, probably in late middle Tertiary time. The streams of the plateau and uplands began again to deepen their valleys and those of the plains and lowlands began to cut new valleys. This process was going on when interrupted by the advance of the Pleistocene ice, and the present features of the bedrock surface, except those due to glacial erosion, date from this time. The surface at this time had much the same form as the present land surface, though probably differing considerably from it in altitude. The position of some of the main drainage lines is fairly well known, though geologists are not agreed as to the direction of the master drainage and its point of ultimate discharge. The depression in part occupied by Lake Erie and in part by the basins of Maumee and Wabash rivers was undoubtedly the main axis of drainage, toward which several streams draining the Allegheny Plateau flowed in general northwesterly courses. The eastern part of the Thumb Upland also was drained southeastward to that valley, and the western part was drained to the Lake Michigan basin, largely by the stream that flowed westward through the Saginaw Lowland.

In the Quaternary period entirely new conditions set in. Great sheets of ice that formed continental glaciers spread outward from centers of accumulation in Labrador and in an area west of Hudson Bay and advanced southward into the United States as far as New Jersey on the Atlantic coast and to the thirty-eighth parallel in southern Illinois. Four or five such ice sheets successively invaded the North Central States and at least two of them—the third or Illinoian and the last or Wisconsin—covered the Lower Peninsula of Michigan. At the time of its greatest extent the Illinoian ice covered about two-thirds of Ohio and five-sixths of Indiana, and between Cincinnati and Louisville it reached a little south of the present course of Ohio River. At both times the ice that covered this region came almost wholly from the center in Labrador and advanced across the region in a general southwesterly direction. As the ice advanced it eroded the surface more or less, making the relief greater in some places and less in others, and it picked up and carried along a great quantity of stones, clay, and sand.

These times of glaciation were separated by interglacial stages when the climate was mild, perhaps milder than at present, and the ice sheets melted away from the region and far back into Canada and may, in fact, have wholly disappeared. As the ice melted, some of the material it had carried along was left where deposited from the ice, and some was carried away by streams flowing from the ice and deposited as outwash. The mantle of glacial drift was several hundred feet thick in places, and in areas of slight bedrock relief it formed an entirely new surface. During the interglacial stages the surface was clothed with vegetation and inhabited by animals, and huge mammals—some of types now extinct, such as the mammoth and the giant sloth—roamed over the plains. During each interglacial stage, as well as since the final disappearance of the ice, a new system of drainage was established on the new surface and dissected it more or less.

In its advance the Wisconsin ice sheet destroyed almost all record of the previous events of Pleistocene time in the area covered by it, but the record of events during its wane is well preserved and is of great interest. The flow of the ice appears to have been spasmodic rather than regular, and times of comparatively rapid advance were separated by intervals of stagnation. At first the forward movement dominated, but after the ice sheet had reached its greatest extent and the climax of the Wisconsin stage had passed the reverse became true, and the ice melted rapidly, the sheet as a whole became much thinner, and during the stagnant intervals its margin retreated a long way. During the short times of renewed flow or reduced melting, however, the ice front again moved forward for some distance, and thus while the ice was disappearing its margin oscillated back and forth across the region, though the dominant movement was that of retreat. At each time of revived activity fresh material was brought forward and deposited where that movement ceased and formed a recessional moraine. A complicated series of such moraines was formed during the disappearance of the Wisconsin ice from the central Great Lakes region, and in areas of slight relief, like the Detroit district, they are the most prominent features of the present topography.

The larger features of the bedrock topography in the region before the ice invasion were much the same as at present and must have affected the flow of the ice, at least locally. At the time of its greatest extent the ice was so thick over the Detroit district that its movement could not have been greatly influenced by the form of the bedrock surface in that neighborhood, but during the wane of the ice sheet, when it had been greatly thinned by melting and its margin had retreated a considerable distance, both the direction of movement and the form of the ice front were practically controlled by the topographic conditions. The ice was held back by the areas of high ground—the Northern Upland and Thumb Upland and the salient points of the Allegheny Plateau—and pushed forward in the areas of low ground—the basins of the present Great Lakes, the Saginaw Lowland, and the low country between the Thumb Upland and the Allegheny Plateau—and the ice margin thus assumed a markedly lobate form. From the farthest points reached by the lobes they built crescentic recessional moraines across the lowlands. The ice spread both ways from the axes of the lobes and carried considerable drift onto the surface of the uplands. Each series of recessional moraines is thus a chain of loops between which are deep reentrants occupied by interlobate morainal deposits of great thickness that have materially increased the altitude of the uplands.

In the vicinity of Detroit there were three such lobes that have affected the history of the district. The Erie lobe moved westward along the valley now occupied by Lake Erie and spread northwestward to Detroit and southwestward into Ohio; the Huron lobe moved south in the southern part of the Huron basin and spread to the east and west; and the Saginaw lobe moved southwestward in the Saginaw Lowland. (See fig. 8, p. 14.) The Thumb Upland was an interlobate area between the three, at first completely covered by ice, but later, when the ice had melted away to the Detroit neighborhood, it barred further advance of the ice and remained bare.

The drainage from the melting ice at first escaped freely to the south and found its way to Mississippi River, but as the ice margin began to retreat northward down the slope to the present drainage basin of the St. Lawrence, the water was ponded in a series of small lakes between the ice and the northern margin of the Allegheny Plateau. As the ice melted back and lower ground was uncovered in front of it the level of these lakes was lowered and at the same time they broadened and united to form the first small representative of glacial Lake Maumee, which soon grew to its full size. This was the first of a long series of glacial lakes that occupied the basin of Lake Erie and more or less of the surrounding territory. During the oscillatory retreat of the ice margin across the Great Lakes region several outlets were successively opened, some of them to be closed again by readvance of the ice, and the drainage of the region immediately about Detroit was first westward into the Mississippi, later eastward into the Mohawk and Hudson, and finally into the St. Lawrence. The water level fell, on the whole, from the first to the last of these lakes, but as a much greater part of the region was free from ice the later lakes were larger than the earlier ones. Most of the lakes lasted long enough for distinct beaches to be built about their shores, and this series of elevated beaches forms one of the most interesting parts of the geologic record in the Detroit district. The history of the lakes and of the formation of the beaches is given in detail under "Geologic history."

The end of the Pleistocene epoch was marked by the final disappearance of the ice from the drainage basin of the Great Lakes. The lakes did not assume their present form and relations for some time after that date, however, as, owing to a progressive uplift of the land to the northeast which followed the disappearance of the ice, outlets were still shifted and the size and level of the lakes changed from time to time. Lake Erie was for a time smaller than at present, and the conditions about Detroit were quite different from those of to-day.

Since the ice disappeared the streams have in places cut through the drift to bedrock and have cut gorges in it, and in other places have partly cleared out the old drift-filled valleys. They have also cut into and terraced the outwash deposits left by the glacial streams and here and there have cut through the recessional moraines and the lake beaches, although the general course of the postglacial drainage has been determined very largely by the position and trend of the beach and morainal ridges. The surface has again been covered with vegetation and rendered habitable. The latest chapter in the history of the region has been the story of its settlement by man, who has taken advantage of geographic and geologic conditions where they were favorable and has to some extent modified them where they were not.

The commercial importance of the Detroit district is due to the combination of favorable conditions already noted. One of these conditions is the abundance of rock salt, anhydrite, and limestone just beneath the surface of the district, another is its situation adjacent to navigable waters, and a third is the proximity of the coal field of the Michigan basin and the forests of the Northern Upland. More important still, however, is its situation at the point of crossing of two great routes of trade.

Perhaps the most important land trade route of the country is that which connects Chicago and the agricultural region of the Middle West by way of Buffalo with New York and the densely settled belt of the Atlantic seaboard. The traffic between these points of course follows more than one route, but the most used route is the one which is naturally the most favorable and which crosses northern Indiana, traverses the Erie-Huron Plain to central New York, and thence follows the Mohawk and Hudson valleys to the sea. It is throughout a low-grade route, traversing plains or valleys and nowhere more than 800 feet above sea level. Some of the railroad lines that follow this route run south and some north of Lake Erie. The northern route, which is shorter, is possible because Lake Erie is separated from Lakes Huron and Ontario by peninsulas and is joined to them, not by broad straits, but by rivers, one of which is easily tunneled and the other easily bridged, thus affording a continuous land route. A great part of the heavy freight therefore takes the northern route, though the bulk of the passenger traffic follows the longer southern route, partly because it is wholly within the United States, but chiefly because it passes through several large cities.

Again, the most important water trade route of the continent is the one which connects ports on the upper Great Lakes with those on Lake Erie and with the Erie and Welland canals. All the traffic, which is heavy in both directions, passes through Detroit River. The Detroit district lies alongside the water route at the point where it is crossed by the northern land route between Chicago and Buffalo, and in a most favorable place for a manufacturing and distributing center.

That two great trade routes cross at this point is due partly to the fact that Lakes Huron and Erie are not a continuous body of water but are separated by a fairly wide land bridge, though joined by a large and deep river, and partly to the fact that the Mississippi Lowland and the Erie-Huron Plain form a continuous low belt between the uplands of the Lower Peninsula of Michigan on one side and the Allegheny Plateau on the other. The land trade routes naturally follow and are concentrated in the lowland belt and are not seriously interrupted by the river that joins the lakes, which is, however, large enough to permit uninterrupted water traffic between the lakes, though confining it to a single line. All the traffic therefore naturally converges at the point where the railroads can reach and cross the river most easily, and at that point Detroit is situated.

The controlling conditions are, therefore, the number, form, and manner of connection of the three lakes—Huron, Erie, and Ontario—and the relief of the surface. The lakes owe their existence to the fact that the region has been glaciated, and their number, outlines, and mutual relations are controlled largely by the recessional moraines formed by the Wisconsin ice sheet during its disappearance from the region. The depressions in which they lie, however, are very largely features of the preglacial relief, which was also the chief factor that affected the flow of the ice and the form of its margin during the building of the moraines and the birth of the lakes. The preglacial relief was the result of the denudation, at times interrupted by uplift, of a region underlain by stratified rocks of different sorts which had been somewhat tilted and warped into arches and basins. Lastly, not only the attitude of the strata but their lithologic differences are due to oscillations of the earth's crust during and after their deposition in Paleozoic time, as such movements affected not only the position of the beds but the conditions under which they were laid down. Back of this it is impossible to go, as the cause of the oscillation of the earth's surface is not known. The present topographic conditions in the region are therefore not only due to the processes that have modified the surface in Mesozoic and Cenozoic time but trace their origin back to the events and processes of early Paleozoic time.

To recapitulate briefly: The oscillations of the earth's crust during and following the deposition of the strata in the Paleozoic era caused the deposits to differ greatly in character and thickness from place to place and from time to time and gave to the accumulated strata slopes away from some areas and toward other areas. Owing to the diverse structure thus produced in the region, its planation in late Mesozoic time, long after final emergence and uplift, produced a surface that was occupied in different parts by rocks of greatly different resistance to erosion. When the region was again uplifted and further denuded a new surface, diversified by uplands and lowlands, was produced. The region was then glaciated, its history during the glaciation being controlled largely by its relief, and the form of its surface and the course of its drainage was greatly modified, and the Great Lakes were formed in the larger and deeper depressions. The final results are the present geographic conditions and relations in the region and their control of its occupation by human beings. The Detroit district, then, in common with the rest of the central Great Lakes region, owes much of its present character and development as the abode of civilized man to events which took place relatively early in geologic time, many millions of years ago.

TOPOGRAPHY.

RELIEF.

General character.—The main topographic features of the district are a moderately hilly morainic belt (see Pl. IV), which occupies the northwest corner, and a rather expressionless plain, which occupies the rest of the area. The two regions are now separated by the old beach of glacial Lake Whittlesey, whose crest within the district ranges from 735 to 740 feet above sea level. Between the beach and the 800-foot contour is a narrow strip which partakes somewhat of the character of each of the two areas but which falls more naturally into the hilly belt.

Hilly belt.—The character of the hilly belt, which occupies only 7 per cent of the surface of the district, is due to numerous clay and gravel knolls and interlocking ridges, whose summits range in altitude from that of the Whittlesey beach up to 960 feet above sea level. The slopes are as a rule gentle (see Pl. IV) and in many places descend to undrained depressions low enough to furnish a local relief of 100 to 125 feet. The highest summits, which are in Novi Township, are nearly 400 feet above Lake Erie, and the total relief in the district is therefore nearly 400 feet. The surface of the hilly belt is more or less strewn with subangular to rounded bowlders and cobbles, disposed in no apparent order. Toward the southeast the knolls and ridges are more subdued and near the Whittlesey beach they merge into the lake plain.

Lake plain.—From an altitude of 720 feet above sea level at the inner margin of the Whittlesey beach the surface descends southeastward to Lake Erie and Detroit River at a slope of approximately 8 feet to the mile. Much of this area appears absolutely flat and featureless, although it has been incised by streams to a maximum depth of 70 feet below the general level. Along the east side of the area, near the lakes and the river, the lake plain merges into low swampy tracts, which lie slightly above the lake level and occupy about 11 square miles. Ridges of sand, and here and there of gravel, having a general northeast-southwest trend, are superposed upon the lake plain. The slopes of the higher mounds and crescentic ridges, which rise 20 to 25 feet above the plain, are steep, and the rise from the outer margin of the lake plain to the crest of the Whittlesey beach is also rather abrupt and conspicuous, as well as strikingly regular.

Detroit interlobate moraine.—A broad, low swell, known as the Detroit interlobate moraine, extends from the vicinity of Birmingham, just north of the district, southeastward across the lake plain. As a topographic feature it is poorly defined and inconspicuous and merges into the lake plain along its flanks. Although quite unrecognizable to the eye, it has, nevertheless, controlled the drainage and has determined the position and trend of the beaches crossing it. Where it enters the district it is approximately 8 miles broad and its crest lies about 700 feet above sea level, but it narrows considerably toward Detroit and its crest descends gradually at an average rate of 6 feet to the mile. Near Detroit River the slope is steeper, 25 feet in a quarter of a mile.

Parallel ridges.—The eastern part of the district, both on the mainland and on many of the islands in Detroit River, is characterized by a series of parallel subdued clay ridges, so evenly spaced, regular, and continuous as in places to resemble corrugations in the surface. The individual ridges are rarely a mile long, die out gradually at their ends, have gentle side slopes, trend in general parallel to the river, and are so disposed that their crests are commonly a fourth to an eighth of a mile apart. The relief from trough to crest ranges from almost nothing in the most subdued ridges to 15 feet in the boldest ones. These ridges are most conspicuous in the northeastern and the southeastern parts of the district and in reality they form a continuous belt, but the middle part of the belt lies across Detroit River in Canada. At the south the belt is about 12 miles broad, but it narrows northward. It is rather generously supplied with bowlders and cobbles. Throughout its course it lies mainly between the 580-foot and 600-foot levels, and the ridges are, therefore, only imperfectly indicated on the topographic maps.

DRAINAGE.

General character.—The drainage of the district is characterized by several noteworthy peculiarities—all the streams are still in the stage of youth; most of them have northeasterly or southeasterly courses; the streams along the eastern border of the district are much younger, both in years and in stage of development, than those in the western part; and the lower ends of the valleys of the streams that flow completely across the district are younger than the middle and upper parts. Another striking characteristic of the streams that flow into Detroit River and the two lakes is their drowned condition near their mouths, where they have sluggish currents, their former banks are submerged, and they are bordered by broad marshy tracts. In the narrow main channels the depth is greater than would be expected for slack-water conditions, the beds of the streams being from 10 to 30 feet below the level of the bodies of water into which they flow. All the larger streams except Detroit River are bordered by relatively broad flood plains, which extend well up to their heads, consist of the ordinary dark alluvial soil, and contain numerous oxbow lakes.

Detroit River.—Receiving as it does the natural drainage from the upper three Great Lakes, the Detroit originates in Lake St. Clair as a stream of magnificent proportions, whose breadth increases from 2,200 feet opposite Detroit to 4 miles where it enters Lake Erie. Its greatest measured depth, opposite Woodward Avenue, in Detroit, is 45 feet. Along the main channels the depth ranges from 18 to 40 feet, being least at Limekiln Crossing. Where it cuts through the Emmet and Grosse Isle moraines, near Detroit and Trenton, the river is dotted by islands, apparently the higher parts of clay or gravel ridges. From the head of Fighting Island to Belle Isle, a distance of more than 9 miles, the river channel lies west of the moraine, contains no islands, and is narrow and deep.

The altitude of the surface, the velocity of the current, and the volume of discharge of the river vary greatly with the levels of the two lakes which it connects, and these levels are in turn dependent on the season, the special climatic conditions, and the force, direction, and duration of the wind. The mean altitude above sea level of the surface of Lake St. Clair is 576.17 feet and that of Lake Erie is 573.11 feet; hence the river has a fall of 3.06 feet, or 0.11 foot to the mile. Opposite Detroit the average surface velocity is approximately 2 miles an hour and the average discharge is 210,000 cubic feet a second. The water ordinarily shows little turbidity, is never laden with much sediment, and contains, in comparison with ordinary streams, little mineral matter in solution.

Tributary streams.—The largest and most completely developed drainage system of the district is that of River Rouge, with its eastern, middle, and southern branches, which unite in a short trunk stream east of Dearborn. Its basin includes nearly all the Wayne quadrangle and about one-half of the Detroit—approximately 320 square miles. Its headwaters rise in the hilly belt, draining the swampy uplands in poorly defined channels or coursing down the flanks of the morainic knolls in sharply cut gullies. Their average fall is from 8 to 11 feet to the mile. The valley of the main stream east of Dearborn is nearly 3,000 feet wide, with broad flood plains 6 to 10 feet above the ordinary river level and banks about 20 feet higher. The stream itself is 40 to 50 feet wide, 8 to 10 feet deep, and generally charged with yellowish sediment. The fall to Detroit River is only 4 feet in 7½ miles, which produces a very sluggish current. At Oakwood a small tributary, now known as Campbell Creek but originally as the East Branch of the Rouge, enters from the north, with its short drowned tributary Knaggs Creek. Near its mouth the Rouge makes a detour to the north and east to reach Detroit River, to which a direct connecting canal about half a mile long was constructed in 1888.

The Huron enters the Romulus quadrangle near Belleville, is deflected eastward for 3½ miles, and thence pursues a general southeasterly though winding course to Lake Erie. The average fall is about 2½ feet to the mile but becomes less toward Rockwood, below which place the stream is drowned. The average depth in midchannel is 12 feet in this part of its course, but depths as great as 30 feet are reported. The mean monthly discharge of the river at Flat Rock ranges from 551 to 820 cubic feet a second, with a minimum of 116 and a maximum of 2,780 cubic feet. Moderately clear during ordinary stages, at flood the stream carries much sediment, and has formed a delta in Lake Erie between 2 and 3 square miles in area. At New Boston the valley is 1,800 feet broad and its banks are 34 feet above the bed of the stream. The modern flood plain is about 12 feet above the bed, with remains of a terrace approximately 8 feet higher, or about 625 feet above sea level. At Flat Rock the valley is 1,600 feet broad, with banks 22 feet high, the stream itself having a breadth of 130 to 140 feet. At South Rockwood the valley has narrowed to 1,400 feet and the stream to 100 feet, with a depth of 7 feet, the altitude being the same as that of Lake Erie.

The southwest corner of the district is crossed by two nearly parallel streams—Swan Creek and Stony Creek—with southeasterly courses into Lake Erie. The north branch of Swan Creek parallels Huron River for about 23 miles, generally only 2 to 4 miles distant but on a higher level. West of Willow the divide between the two is less than a quarter of a mile across.

In the eastern part of the district a number of minor streams flow directly into Detroit River. Named in order, from south to north, they are Brownstown, Big Marsh, and Monguagon creeks, on the mainland, and Frenchmans Creek, on Grosse Isle, Ecorse River (with its three branches), Conners Creek, and Fox Creek. Within the present limits of Detroit two other streams—Savoy Creek and Bloody Run—have been in large part obliterated by grading and sewers. In the main these streams are youthful, have rather straight courses, are intermittent for considerable distances, have no branches, and do little cutting. Conners Creek has a fall of about 60 feet, an average of 6 feet to the mile, and in the middle part of its course has banks 12 to 18 feet high. All, like the larger streams, are drowned near their mouths.

Ponds and swamps.—In striking contrast to the adjacent parts of Oakland and Washtenaw counties the Detroit district is deficient in ponds and small lakes. Aside from the numerous oxbow lakes or bayous, on the river flats, Yerkes Lake is the only natural inland lake. It lies about a mile east of Northville, is approximately 1,170 feet long by 840 feet wide and elliptical in outline, and has an average depth of 28 feet, and, so far as known, a maximum depth of 39 feet. It is fed by springs, is surrounded in part by swamps, and at high stages drains southwest into the Middle Rouge.

Where the streams are dammed ponds are formed, which give rise to swampy conditions about their margins. The largest such pond is at Belleville. Other small artificial ponds occupy hollows and abandoned excavations at many places.

Although the topography of the district is such that practically no natural lakes have been formed, the minor surface features have obstructed the drainage sufficiently to give rise to extensive marshes. Those bordering Lake Erie, Detroit River, and the drowned lower courses of some of the streams have already been mentioned. Drainage and cultivation have done much toward the obliteration of the marshy areas, which impeded travel in the early days of the settlement of the region, served as breeding places for mosquitoes, and greatly retarded the development of the State. The topographic map issued by the first Geological Survey of the State shows the location of the principal formerly marshy areas in Wayne County, and a comparison of it with the topographic maps in this folio shows the extent to which the marsh lands have been reclaimed by drainage.

CULTURE.

The population of the district in 1910, according to the census of that year, was approximately 542,000, chiefly concentrated along Detroit River. In 1915 (July) the principal city, Detroit, was credited with a population of approximately 555,000. Wyandotte—more than 9,000 inhabitants in 1915—is the only other city, but the district includes also 20 incorporated villages. The strictly rural population averages about 50 to the square mile, or about one family to 65 acres.

Detroit is an important manufacturing center. The clay-working, salt, alkali, and soda-ash industries in the neighborhood, as well as the limestone quarries in the lower Detroit River region, also furnish employment to a large number of workmen. The chief industry of the rural population is agriculture, including truck gardening, fruit growing, and dairying.

Numerous lines of steam and electric railways radiate from Detroit, and Detroit River is one of the great waterways of the world, its annual tonnage exceeding that of the Suez Canal. To obviate the frequent ice blockades experienced in ferrying cars between Detroit and Windsor during the winter the Michigan Central Railroad has constructed a double tunnel beneath the river, through which trains are drawn by electric motors. The district is well covered by a network of highways, which, owing to the character of the soil, were formerly in poor condition, especially at certain seasons of the year; but an elaborate system of gravel, concrete, and macadam roads is now in process of construction. Most of the roads follow township and section lines, being shifted here and there, however, to take advantage of the topography. In a strip along the banks of Lake St. Clair and upper Detroit River the main roads are parallel or perpendicular to the boundaries of the old French claims. This is also true of the streets of Detroit, scarcely one of which runs north and south or east and west.

DESCRIPTIVE GEOLOGY.

STRATIGRAPHY.

CHARACTER OF ROCKS.

The rocks of the Detroit district, which are all sedimentary, comprise indurated strata of Paleozoic age and unconsolidated surficial deposits of Quaternary age. The latter, which consist of till, gravel, sand, and clay, include glacial, fluviatile, and lacustrine deposits of Pleistocene age and lacustrine and alluvial deposits of Recent age. They attain a thickness of 200 feet or more and occupy the entire surface of the northwestern part of the district and most of that of the remainder, the natural exposures of bedrock being few and scattered.

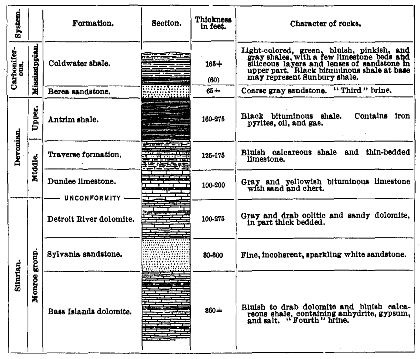


FIGURE 5.—Generalized section of the rocks that form the surface beneath the drift in the Detroit district, as determined by the Michigan Geological Survey.

Scale: 1 inch=500 feet.

The later Paleozoic strata, which outcrop at the surface or immediately underlie the drift, consist of dolomite, limestone, shale, and sandstone, and range in age from late Silurian to early Carboniferous (see fig. 5), though a considerable part of the Devonian system is not represented. Their distribution beneath the drift is shown in the bedrock-geology map. All these formations thicken northwestward, and their combined thickness in the district ranges from about 1,000 feet in the southeastern to perhaps 1,600 feet in the northwestern part.

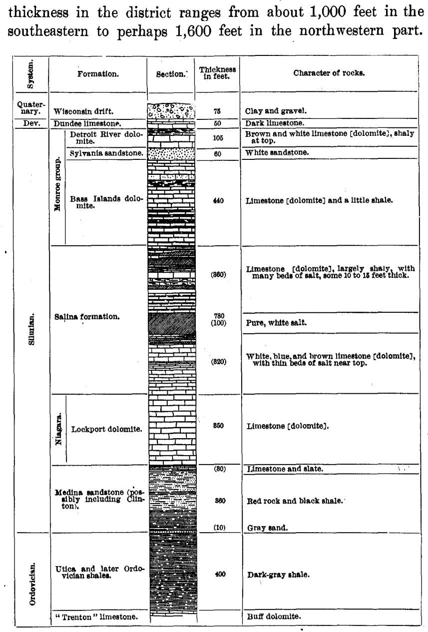


FIGURE 6.—Section of Eureka deep well at Wyandotte, Mich.

From Michigan Geol. Survey, vol. 5; reinterpreted by the author.

Scale: 1 inch=500 feet.

NOTE.—Since this text was written a well at Dearborn, Mich., has been sunk by H. R. Ford to a depth of 4,085 feet. The log of this well has been interpreted by R. A. Smith, of the Geological Survey of Michigan, as shown below. The modifications in brackets were made by E. O. Ulrich.

Strata penetrated in well at Dearborn, Mich.

	Feet.
Pleistocene	125
Dundee limestone	90
Detroit River dolomite	280
Sylvania sandstone	125
Bass Islands dolomite	870
Salina formation	1,235
Niagara group	100
Medina to Utica shale	725
"Trenton" limestone [mainly Black River]	875
Beekmantown dolomitic sandstone [St. Peter?]	110
Depth	4,085

Beneath the formations that outcrop or directly underlie the drift within the district are other strata of Silurian and Ordovician age, at least 2,000 feet thick, as revealed by deep borings in and adjacent to the district. These are, in all probability, underlain by still older Paleozoic strata, the whole resting on a floor of pre-Cambrian crystalline rocks.

The sequence, age, approximate thickness, and general character of the indurated rocks that directly underlie the drift of the district are shown graphically in the columnar section (fig. 5), which is a generalized section for the whole district. The record of the deepest well in the district, from which knowledge of the older strata is derived, is shown graphically in figure 6. The several formations will be described in detail in their order of age, beginning with the oldest.

ORDOVICIAN SYSTEM.

"TRENTON" LIMESTONE.

The oldest formation entered by the deep wells of southeastern Michigan is the "Trenton" limestone, which was reached in the Eureka well at Wyandotte and in several of the deepest wells in Monroe County, south of the Detroit district, but in each well was entered for only a few feet. The rock encountered in these wells is a buff dolomite. At Wyandotte the top of the formation lies at a depth of about 2,600 feet, or somewhat more than 2,000 feet below sea level. By comparing this depth with that at which the formation is encountered in wells near Monroe its surface is found to descend northeastward at an average rate of 42 feet to the mile and as the dip is to the northwest the descent in that direction must be at an even greater rate. None of the deep wells of southeastern Michigan has passed through the formation, so its thickness in that region is not known.

UTICA AND LATER ORDOVICIAN SHALES.

Before reaching the top of the "Trenton" the borings pass through a body of bluish to grayish, more or less calcareous shale, which in the Eureka well is 400 feet thick and which is believed to be the equivalent of the Utica shale and later Ordovician formations of New York. The shale can not be divided in the well sections, but the darker and more bituminous lower part is regarded as Utica.

SILURIAN SYSTEM.

MEDINA AND NIAGARA FORMATIONS.

The Ordovician strata are overlain by about 350 feet of red and black shale containing a few thin beds of limestone, dolomite, and sandstone, which are regarded as the equivalent of the Medina and possibly the Clinton of New York, but the formations can not be satisfactorily separated in this region. In the Eureka well the top of the red shale was reached at a depth of 1,890 feet, or approximately 1,300 feet below sea level, and it is overlain by 30 feet of limestone and limy shale, the latter regarded by Lane as equivalent to the Rochester shale member of the Clinton of New York. This in turn is overlain by 350 feet of hard, compact fine-grained light-colored dolomite, which is presumably the equivalent of the Lockport dolomite of New York. The Clinton and the Lockport constitute the Niagara group. Well records in Monroe County indicate that the shale thickens southward and that the dolomite becomes thinner.

SALINA FORMATION.

In the Detroit district the Salina formation consists of alternate beds of compact brown to drab dolomite, rock salt, anhydrite or gypsum, and thin layers of bluish-black shale. As it contrasts strongly in color with the underlying Niagara, which contains no beds of shale, rock salt, or gypsum, its base is well defined. Its top, however, is less definite, and the separation from the overlying Monroe group is made arbitrarily at the top of the uppermost well-defined bed of rock salt or anhydrite.

The formation undoubtedly underlies the whole district, and as it is economically the most important formation therein it has been entered by many deep wells along Detroit River, few of which, however, have passed through it. In the Eureka well the thickness of the formation, between the limits just assigned, is about 780 feet and the aggregate thickness of the salt beds is 160 feet. The formation thickens northward and at Royal Oak is at least 932 feet thick, 609 feet of which is reported as rock salt. The most satisfactory section of the formation was furnished by the Oakwood salt shaft and boring (see fig. 19, p. 19), where a preliminary boring showed the formation to be at least 929 feet thick, with an aggregate of about 600 feet of rock salt. In the lower Detroit River region the place of the salt appears to be taken by beds of anhydrite, the salt giving out completely at the abandoned soda-ash plant of Church & Co., just north of Trenton.

MONROE GROUP.

GENERAL CHARACTER.

The Monroe group, which includes the uppermost Silurian strata, overlying the Salina formation, comprises the oldest rocks that outcrop in the Detroit district. It is 500 to 600 feet thick and consists chiefly of dolomite but contains some thin limestone and shale members and, near the middle, about 165 feet of snow-white sandstone. It was formerly regarded as a single formation, with a sandstone member called the Sylvania sandstone in the middle, and the parts of the formation below and above the sandstone were known respectively as the "Lower Monroe" and "Upper Monroe." It has seemed advisable, in view of the faunal differences between the "Lower Monroe" and the "Upper Monroe," of their complete separation by the Sylvania sandstone, and of the sharp lithologic difference between the sandstone and the underlying and overlying beds, to regard the Monroe as a group comprising three formations—the Bass Islands dolomite at the base, the Sylvania sandstone in the middle, and the Detroit River dolomite at the top. In publications of the Michigan Geological Survey the divisions indicated by these names are regarded as members, but in this folio they are regarded as formations. (See fig. 5.)

BASS ISLANDS DOLOMITE.

Definition and thickness.—The Bass Islands dolomite, so named from the Bass Islands in Lake Erie, where the formation is typically exposed, includes the strata, consisting of dolomite with intercalated thin beds of oolite and of breccia, which lie between what is regarded as the top of the Salina formation and the base of the Sylvania sandstone and which were formerly known as the "Lower Monroe." Where the Sylvania is not present its horizon is indicated by an arenaceous dolomite, so that the top of the formation may be recognized with considerable accuracy in sections and borings. The separation of the base of the formation from the underlying Salina strata is rather difficult, however, because of the lithologic similarity of the two and the general absence of fossils. Ordinarily it is rather arbitrarily made at the top of the uppermost thick bed of gypsum, anhydrite, or rock salt. In the 17 wells of the Solvay Process Co., near the mouth of Rouge River, the average thickness of the formation as thus defined is 360 feet. In the Eureka well at Wyandotte it is 440 feet.

Distribution. — The formation underlies the drift in the southern part of the Wyandotte quadrangle, mainly in Monroe County. It is not exposed at the surface, either naturally or artificially, anywhere in the Detroit district, but it is exposed in numerous outcrops and quarries in the adjacent territory on the south. The quarry at Newport, just outside the district, now abandoned and filled with water, furnished a good section of the upper members and a collection of fossils. The formation dips to the north and northwest and underlies the younger Paleozoic beds throughout the district.

Character and subdivisions.—The formation consists of brown to drab thin-bedded dolomite, with about the normal proportions of calcium and magnesium carbonates and ordinarily 1.5 to 3 per cent of silica, alumina, and iron oxide. At certain horizons the thin slabs bear ripple marks and mud cracks. Brecciation along joint planes and in cavities is not uncommon, in places involving the entire thickness of a stratum. Large hemispherical masses, having a finely laminated concentric structure and resembling gigantic Stromatopora but apparently of concretionary origin, are exposed here and there in the bottoms of quarries. Patches of pyrite are scattered through the beds, and the cavities and seams contain well-crystallized masses of calcite and celestite.

A feature of the formation is the occurrence of several oolitic strata, each underlain by a peculiar bed of blotched, mottled, and streaked dolomite. This dolomite is compact, brittle, light gray, with conchoidal fracture, and free from fossils. The blotches and streaks are blue, except when weathered to rusty brown, which indicates the presence of iron compounds.

The formation has been subdivided into the following members, of which only the uppermost, the Raisin River dolomite member, forms any of the bedrock surface beneath the drift in the Detroit district: Raisin River dolomite member, Put in Bay dolomite member, Tymochtee shale member, Greenfield dolomite member. (See fig. 19, p. 19.) Immediately south of the Detroit district the Raisin River and Put in Bay members are found, but the Tymochtee and Greenfield members have not been determined to be present.

Relations.—The Oakwood salt shaft penetrated the entire thickness of the formation, but no opportunity was afforded for observing satisfactorily the contact between it and the adjoining formations. At the top the separation from the Sylvania sandstone is sharp, and the relation between the two seems to be that of unconformity. The base of the formation appears to be conformable with the underlying Salina beds, but the relation there also is believed to be that of unconformity.

Fossils.—The fairly abundant fossils of the formation have been studied by A. W. Grabau, who has listed the following species in a report on the Monroe formation:[1]

- Pholidops cf. P. ovata Hall.
- Schuchertella hydraulica Whitfield.
- Schuchertella interstriata (Hall).
- Camarotoechia hydraulica Whitfield.
- Camarotoechia sp.
- Rhynchospira praeformosa Grabau.
- Spirifer ohioense Grabau.
- Hindella whitfieldi Grabau.
- Hindella rostralis Grabau.
- Hindella? rotundata (Whitfield).
- Whitfieldella prosseri Grabau.
- Whitfieldella subsulcata Grabau.
- Meristina profunda Grabau.
- Meristina profunda sinosus Grabau.
- Pterinea lanii Grabau.
- Goniophora dubia Hall.
- Tellinomya sp.
- Modiomorpha sp.
- Solenospira minuta (Hall).
- Loxonema sp.
- Holopea sp. 1.
- Holopea sp. 2.
- Holopea sp. 3.
- Cyrtoceras orodes Billings.
- Spirorbis laxus Hall.
- Leperditia angulifera Whitfield.
- Leperditia altoides Grabau.
- Leperditia alta Conrad.
- Kloedenia monroensis Grabau.
- Eurypterus eriensis Whitfield.
- Sphaerococcites? glomeratus Grabau.

The fossils are most abundant in the upper part of the formation and are relatively scarce in the lower members. The formation lacks entirely the coral and stromatoporoid fauna so abundant in the Detroit River dolomite and is relatively deficient in gastropods and cephalopods. Brachiopods and pelecypods are more numerously represented. The pelecypod *Pterinea lanii* is abundant, well preserved, and easily recognized, but the most characteristic fossil is the small brachiopod *Whitfieldella prosseri.* The Raisin River dolomite member is regarded by Grabau as closely related faunally to the Manlius and Rondout limestones of New York.

SYLVANIA SANDSTONE.

Definition and thickness.—The Sylvania sandstone, named from Sylvania, Lucas County, Ohio, overlies the Bass Islands dolomite and is in turn succeeded by the Detroit River dolomite. As it consists of white sandstone, it is readily recognized and in borings is easily differentiated from the other two formations of the group. In the 17 wells of the Solvay Process Co., near Detroit, it ranges in thickness from 70 to 165 feet, the average thickness being 93 feet. Northwestward, in the direction of the dip, the thickness increases to nearly 300 feet and southeastward and southward it decreases to 30 feet.

Distribution.—The formation does not outcrop anywhere in the Detroit district and its distribution is known only from the artificial exposures in numerous shallow wells and in the pit near Rockwood. It occupies a belt, 2 to 3 miles wide, of the bed-rock surface beneath the drift, which swings in from Monroe County, curves eastward across the southern townships of the district, and apparently crosses Detroit River at its mouth. The strata dip to the northwest and north beneath all the younger formations of the district, and the sandstone is encountered in all wells that are deep enough to reach its horizon.

Character.—The formation is typically a sandrock consisting of a remarkably homogeneous sparkling snow-white aggregation of loosely cohering quartz grains. It is often compared by drillers to snow, flour, salt, and granulated sugar. It is rather friable, and when the less coherent varieties are placed in water they fall apart like some kinds of clay. The small amount of cement consists of dolomitic material, apparently deposited from percolating water. Where immediately overlain by drift the rock is commonly strongly discolored by iron oxide to a depth ranging from a few inches to several feet. In places the rock is cemented by silica and is typical sandstone or even grades into quartzite. The proportion of silica in the rock is generally more than 96 per cent, and after the crushed rock has been washed the sand so cleaned runs more than 99 per cent silica.

Wherever the formation has been exposed in open pits a poorly defined and irregular stratification is displayed, the beds ranging in thickness from a few inches to several feet. They are level or only gently inclined and everywhere show a distinct lamination, the angle between the lamination and the bedding being as much as 30° in places. The lamination is indicated by slight differences in color and texture and in places it is wavy as well as diagonal to the bedding. In the pit at Rockwood and elsewhere oblique partings are displayed, which make about the same angle with the bedding as the most steeply inclined laminae but are not observed to be conformable with them.

Examination with the microscope shows that the sand grains are remarkably well rounded and sorted, especially in the upper layers at the Rockwood pit. Many grains have been enlarged by the deposition of secondary silica in optical continuity with the original quartz, resulting in the formation of minute doubly terminated crystals with sharp edges and complete faces. To this is due the sparkling appearance of the sand, its scouring qualities, and its rapid cutting of drills and pump valves. The grains not so enlarged have frosted and pitted surfaces, similar to those of typical grains of desert sand. In view of the extent and thickness of the formation the individual grains are remarkably fine and of uniform size, as is shown by mechanical analyses.[2]

In several places the formation is divided by a bed of dolomite, the so-called "Sylvania dolomite," which in the Detroit district ranges in thickness from 30 to 105 feet. According to the logs of a number of wells, in some places two or even three such beds are included in the formation. The dolomite contains grains of sand seemingly identical with those of the sandstone. The proportion of silica in the rock is not uniform but commonly ranges from 50 to 70 per cent.

The formation rests upon the Bass Islands dolomite in apparent conformity, but there is some reason for believing that the true relation is that of unconformity. This is inferred from the supposed origin of the formation.

Fossils and age.—The body of the formation is quite barren of fossils wherever exposed, their former presence being suggested only by carbonaceous partings. The uppermost beds contain obscure traces of plant remains, and compressed *Paracyclas*-like casts are abundant in certain layers, the white sand of which they are composed contrasting strongly with the carbonaceous films surrounding them. Marine fossils occur sparingly in the dolomite lenses, and among the species that have been identified are *Cladopora bifurcata* Grabau and *Favosites basaltica* var. *nana* Grabau. Both of these are found also in the overlying Detroit River dolomite. Its position in the middle of the Monroe group fixes the age of the Sylvania sandstone as late Silurian.

DETROIT RIVER DOLOMITE.

Definition and thickness. — The Detroit River dolomite, formerly known as the "Upper Monroe," or the "Detroit River series," includes the beds, consisting chiefly of dolomite, between the top of the Sylvania sandstone and the base of the Dundee limestone of Devonian age. The presence of the Anderdon limestone member, with its high content of calcium carbonate, has led to error in the interpretation of well records along Detroit River, especially in sections in which the Lucas and Amherstburg dolomite members are missing, having been removed by erosion, so that the Dundee limestone rests directly upon the Anderdon member.

In northwestern Ohio the Lucas dolomite member in its type locality rests directly on the Sylvania sandstone, and the beds which intervene in Michigan are missing on account of overlap. The thickness of the formation appears to be about 100 feet at Wyandotte and 274 feet at Oakwood. From records obtained in localities outside the district it is inferred that the thickening continues for some distance to the north.

Distribution and exposure.—The formation occupies a belt, from 2 to 5 miles wide, of the bedrock surface beneath the drift, extending from the south side of the Romulus quadrangle northeastward and thence eastward across the southern part of the Wyandotte quadrangle. It outcrops on Celeron and Stony islands and Grosse Isle, and, for a short distance, forms the ledges in the bed of Huron River at Flat Rock. It has been exposed to a depth of 25 feet in the Patrick and Gibraltar quarries and was laid bare in making the cut for the Livingstone Channel in Detroit River, as is shown in Plate I. The beds dip gently to the northwest and north and extend beneath all the younger formations of the district.

Character and subdivisions.—The formation consists chiefly of dolomite, which is lithologically indistinguishable from the Bass Islands dolomite. The oolitic beds, however, are not so numerous, and the celestite, calcite, and sulphur associated with the strata and deposited in the cavities are more abundant. The formation is, moreover, characterized by an intercalated bed of limestone, the Anderdon limestone member, much of which is of high grade and parts of which appear to have been a veritable coral reef. Selected samples which have been analyzed contained more than 99 per cent of calcium carbonate.

The formation has been subdivided into four members—the Flat Rock dolomite member at the base, overlain in turn by the Anderdon limestone member, the Amherstburg dolomite member, and the Lucas dolomite member at the top. (See fig. 19, p. 19.) The Lucas member comprises about three-fifths of the whole thickness of the formation, and the Anderdon and Amherstburg members are thin. The members are not everywhere present, the upper two in particular being absent from many sections.

Relations.—In the limited sections that have been observed the formation appears to overlie the Sylvania sandstone conformably, but its irregular thickness and the absence of some of its members from some sections in the Detroit River region are evidences of a marked unconformity between the two, and the numerous well records indicate that the four members of the formation overlap successively on the eroded surface of the Sylvania. In some places, north of the Detroit district, the Sylvania sandstone is missing, or is represented only by siliceous dolomite, and the Detroit River dolomite appears to rest directly upon the Bass Islands dolomite.

Fossils and correlation.—The formation is rich in fossils, of which the following species are listed by Grabau:[3]

- Clathrodictyon ostiolatum (Nicholson).
- Clathrodictyon variolare (Von Rosen).
- Stromatopora galtensis (Dawson).
- Coenostroma pustulosum Grabau.
- Stylodictyon sherzeri Grabau.
- Idiostroma nattressi Grabau.
- Helenterophyllum caliculoides Grabau.

[1] Grabau, A. W., and Sherzer, W. H., The Monroe formation of southern Michigan and adjoining regions: Michigan Geol. and Biol. Survey Pub. 2, pp. 211-213, 1910.

[2] Grabau, A. W., and Sherzer, W. H., op. cit., p. 77.

[3] Grabau, A. W., and Sherzer, W. H., op. cit., pp. 211-213.

Cyathophyllum thoroldense Lambe.
Heliophrentis alternata Grabau.
Heliophrentis alternata var. compressa Grabau.
Heliophrentis alternata var. magna Grabau.
Heliophrentis carinata Grabau.
Cylindrohelium profundum Grabau.
Cylindrohelium heliophylloides Grabau.
Cystiphyllum americanum var. anderdonense Grabau.
Acervularia sp.
Synaptophyllum multicaule (Hall).
Diplophyllum integumentum (Barrett).
Romingeria umbellifera (Billings).
Ceratopora regularis Grabau.
Ceratopora tenella (Rominger).
Favosites basaltica var. nana Grabau.
Favosites rectangularis Grabau.
Favosites tuberoides Grabau.
Favosites concava Grabau.
Favosites cf. F. maximus (Troost).
Cladopora bifurcata Grabau.
Cladopora cf. C. cervicornis Hall.
Cladopora sp.
Syringopora microfundulus Grabau.
Syringopora cooperi Grabau.
Syringopora hisingeri Billings.
Fenestella sp. 1.
Fenestella sp. 2.
Prosserella lucasi Grabau.
Prosserella subtransversa Grabau.
Prosserella subtransversa var. alta Grabau.
Prosserella unilamellosa Grabau.
Prosserella planisinosa Grabau.
Whitfieldella sp.
Meristospira michiganensis Grabau.
Atrypa reticularis (Linnaeus).
Panenka canadensis Whiteaves.
Pterinea bradti Grabau.
Goniophora sp.
Cypricardinia canadensis Grabau.
Conocardium monroicum Grabau.
Hormotoma subcarinata Grabau.
Hormotoma tricarinata Grabau.
Solenospira minuta (Hall).
Solenospira extenuatum (Hall).
Loxonema parvum Grabau.
Holopea subconica Hall.
Holopea antiqua var. pervetusta (Hall).
Pleurotrochus tricarinatus Grabau.
Acanthonema holopiforme Grabau.
Acanthonema holopiforme var. obsoletum Grabau.
Acanthonema laxum Grabau.
Acanthonema newberryi (Meek).
Strophostylus cyclostomus Hall.
Pleuronotus subangulatus Grabau.
Euomphalus cf. E. fairchildi Clarke and Ruedemann.
Eotomaria areyi Clarke and Ruedemann.
Eotomaria galtensis (Billings).
Eotomaria sp.
Lophospira bispiralis (Hall).
Euomphalopterus cf. E. valeria (Billings).
Schuchertella interstriata (Hall).
Schuchertella amherstburgensis Grabau.
Stropheodonta vasculosa Grabau.
Stropheodonta demissa var. homolostriata Grabau.
Stropheodonta praeplicata Grabau.
Stropheodonta sp.
Camarotoechia semiplicata (Conrad).
Spirifer sulcatus var. submersus Grabau.
Spirifer modestus Hall.
Prosserella modestoides Grabau.
Prosserella modestoides var. depressa Grabau.
Pleurotomaria cf. P. velaris Whiteaves.
Trochonema ovoides Grabau.
Poleumita cf. P. crenulata (Whiteaves).
Hercynella canadensis Grabau.
Orthoceras cf. O. trusitum Clarke and Ruedemann.
Dawsonoceras annulatum var. americanum (Foord).
Cyrtoceras orodes Billings.
Poterioceras cf. P. sauridens Clarke and Ruedemann.
Trochoceras anderdonense Grabau.
Cornulites arcuatus Conrad.
Proetus crassimarginatus (Hall).

Compared with the Bass Islands dolomite the formation is strikingly rich in stromatoporoids, corals, brachiopods, gastropods, and cephalopods. The most interesting feature of the fauna is the commingling of Silurian and Devonian forms, which reaches its climax in the Anderdon limestone member. This mixed fauna is rich in corals and stromatoporoids, *Stylodictyon sherzeri* Grabau and *Idiostroma nattressi* Grabau being regarded as diagnostic forms. In the Lucas dolomite member corals are poorly represented, although *Cylindrohelium profundum* Grabau is characteristic, but gastropod molds are very abundant at certain horizons, *Hormotoma* and *Acanthonema* being especially numerous.

According to Grabau, the Lucas member is to be correlated with the combined Manlius and Rondout limestones of New York and the Amherstburg and Anderdon members with the Cobleskill and Rosendale of New York. The Rosendale of eastern New York is, however, included in the underlying Salina. The Flat Rock dolomite member is, so far as known, not represented in New York.

DEVONIAN SYSTEM.

GENERAL CHARACTER.

The Devonian system is represented in the Detroit district by three formations—the Dundee limestone, the Traverse formation, and the Antrim shale—of Middle and Upper Devonian age and in general equivalent to Devonian formations of New York from the Onondaga to the Portage and probably later Devonian. The Lower Devonian and the lower part of the Middle Devonian are not represented by any formations in the district.

DUNDEE LIMESTONE.

Definition and thickness.—The Dundee limestone includes the fairly homogeneous strata between the Detroit River dolomite and the bluish shale and limestone of the Traverse formation. Its upper limit is well defined, even in borings, but its base can not everywhere be recognized so readily, as it is somewhat magnesian in some places, and in others, where the Lucas and Amherstburg members of the Detroit River dolomite are lacking, it rests directly upon the Anderdon limestone member, from which it can be distinguished only by its fossils. Ordinarily, in the well records, it is to be assumed that the Lucas and the Amherstburg members overlie the Anderdon member; in such cases the base of the Dundee is placed at the break between the more or less magnesian limestone and the underlying true dolomite.

No complete sections of the formation are available in the Detroit district, but from measurement obtained at localities just outside it appears to be 100 feet thick along the south side and 200 feet thick along the north side of the district.

Distribution.—The formation does not outcrop in the Romulus quadrangle, but, so far as can be learned from the well records, it occupies a belt of the bedrock surface beneath the drift from 3 to 7 miles wide and trending from southwest to northeast across the quadrangle. In the Wyandotte quadrangle the belt broadens and occupies the northern half of the quadrangle. The formation extends northeastward along Detroit River almost or quite to Belle Isle, and it formerly outcropped where the Sibley quarry is now located. This quarry is nearly 100 acres in extent and displays a section of almost the whole thickness of the formation.

Character.—The formation consists of gray to bluish limestone, ranging from massive to thin-bedded, and a few thin layers of chert. Some of the beds near the base are magnesian, but the rock rarely contains more than 15 per cent of magnesium carbonate. The purer and more desirable limestone is in the upper part of the formation, and from some of the beds rock is taken that runs more than 98.5 per cent calcium carbonate in carload lots. A few beds contain silicified fossils and nodules of chert. Much of the rock has a characteristic odor of petroleum and some small cavities contain a few drops of thick black oil. The following section, displayed in the Sibley quarry, is typical of the formation:

Section of Dundee limestone in Sibley quarry.

	Ft.	in.
Limestone, yellow, brown, or gray, thin bedded, very fossiliferous	6	0
Limestone, gray to bluish, thin bedded	7	0
Limestone, gray, compact, rich in fossils	2	0
Limestone, bluish, compact, crystalline	5	0
Limestone, gray to blue, compact; abundant fossil fragments	6	0
Chert, bluish gray, brittle; some fossils	1	2
Limestone, gray to bluish, thick bedded	6	0
Chert, impure, very brittle; some fossils	2	0
Limestone, blue to gray, compact, thick bedded	9	0
Limestone, magnesian, oily	6	0
Limestone, gray, thin bedded, fossiliferous	8	0
Limestone, magnesian, light to dark gray; fossils	12	0
Limestone, siliceous, thin bedded, firm; few fossils	7	0
	77	2

Analyses of drill cores from borings that penetrated the lowermost 30 to 40 feet of this section show that the rock of the lower part of the formation contains from 75 to 93 per cent of calcium carbonate, from 2.5 to 15 per cent of magnesium carbonate, and from 0.7 to 9.5 per cent of silica. The transitional character of the basal bed, which here rests on the Anderdon limestone member of the Detroit River dolomite, is indicated by its high content of silica, due to the presence of abundant quartz grains which make up nearly one-tenth of the bulk of the rock.

Relations.—The Dundee rests unconformably upon the Detroit River dolomite, but in restricted sections the unconformity is not apparent. Where the two formations are examined over wide areas a discordance in dip may be detected, as Lane has pointed out. The unconformity is fully demonstrated, however, by the fact that the formation rests on the Anderdon member of the Detroit River dolomite at the Sibley quarry, on the Sylvania sandstone in Monroe County and in northern Ohio, and on the Bass Islands dolomite in other localities.

Where the formation rests directly on the Anderdon limestone member its base consists of a few inches of white sandstone or about a foot of sandy limestone containing quartz grains of apparently the same sort as those making up the Sylvania sandstone.

Fossils and correlation.—The purer limestones of the formation are very rich in fossils, which are excellently preserved. Extensive collections have been made from the beds in the Sibley quarry and have been studied by Grabau,[1] whose lists include the following species. Comparison with lists of the species found in other localities indicates that fuller search will bring to light numerous other forms.

Zaphrentis convoluta Hall.
Zaphrentis prolifica Billings.
Zaphrentis cornicula Edwards and Haime.
Aulacophyllum sulcatum Etheridge and Hall.
Cystiphyllum vesiculosum Goldfuss.
Acervularia rugosa.
Eridophyllum simcoense.
Favosites turbinata Billings.
Favosites emmonsi Rominger.
Cladopora cf. C. cryptodens Billings.
Clathrodictyon cellulosum Nicholson and Murie.
Fenestella planidorsata Ulrich.
Atrypa reticularis Linnaeus.
Atrypa spinosa Hall.
Cyrtina hamiltonensis Hall.
Cyrtina hamiltonensis var. recta.
Spirifer bidorsalis Winchell.
Spirifer gregarius Clapp.
Spirifer grieri Hall.
Spirifer manni Hall.
Spirifer oweni Hall.
Sanguinolites sanduskyensis Meek.
Actinodesma erectum Conrad
Conocardium trigonale Hall.
Cystodictya gilberti (Meek).
Stropheodonta inaequiradiata.
Stropheodonta dundeensis Grabau.
Stropheodonta hemispherica Hall.
Stropheodonta concava Hall.
Stropheodonta costata Owen.
Stropheodonta fissicostata Winchell.
Stropheodonta demissa (Conrad).
Stropheodonta alpinensis Grabau.
Stropheodonta perplana (Conrad).
Stropheodonta iowaensis (Owen).
Leptaena rhomboidalis (Wilckens).
Schuchertella arctostriata Hall.
Chonetes mucronatus Hall.
Chonetes gibbosus Hall.
Chonetes deflectus Hall.
Stropholosia truncata Hall.
Productella spinulicostata Hall.
Rhipidomella variabilis Grabau.
Rhipidomella vanuxemi Hall.
Rhipidomella penelope Hall.
Rhipidomella livia Billings.
Schizophoria iowaensis Hall.
Schizophoria propinqua Hall.
Pentamerella cf. P. pavilionensis.
Actinopecten decussata Hall.
Aviculopecten similis (Whitfield).
Aviculopecten sp.
Paracyclas elliptica Hall.
Pleurotomaria lucina Hall.
Harmotoma maia Hall.
Coelidum sp.
Euomphalus decewi Billings.
Trochonema meekanum Miller.
Platyceras dumosum Conrad.
Platyceras attenuatum Meek.
Platyceras carinatum Hall.
Callonema bellatulum Hall.
Tentaculites scalariformis Hall.
Trematoceras ohioense Whitfield.
Gyroceras ohioense Meek.
Gyroceras inelegans Meek.
Nautilus inopinatus Hall.
Poterioceras amphora Whitfield.
Poterioceras hyatti (Whitfield).
Proteus conicus Grabau.
Proteus crassimarginatus Hall.
Proteus planimarginatus Grabau.
Dalmanites calypso Hall and Clarke.
Phacops rana Green.

[1] Grabau, A. W., Preliminary report on the fauna of the Dundee limestone of southern Michigan: Michigan Geol. and Biol. Survey Pub. 12, pp. 327–378, 1913.

Grabau calls attention to the intermediate and comprehensive character of the Dundee fauna, which is made up of Onondaga and Hamilton forms, of Middle Devonian age. The pelecypods and cephalopods show Onondaga affinities, the corals and gastropods indicate an intermediate position, and the brachiopods and trilobites incline toward the Hamilton. He therefore prefers to combine the Dundee with the Traverse formation in a single group, which he calls the Traverse group. The Devonian limestone on the island of Mackinac (the Mackinac limestone of early reports) he regards as older than the Dundee and more nearly the equivalent of the Schoharie and the Onondaga of New York.

TRAVERSE FORMATION.

Definition.—The Traverse formation consists of limestone to which various names have been applied by the Michigan Geological Survey. It takes its present name from its excellent exposure in the Grand and Little Traverse districts of Michigan. It is rather sharply set off by the pure gray Dundee limestone beneath and the black Antrim shale above.

Distribution and thickness.—The formation is not exposed in the district. So far as can be made out from the available well records its outcrop beneath the drift crosses the district diagonally from the middle of the west side of the Romulus quadrangle to Grosse Pointe and occupies a belt 2 to 5 miles wide lying next northwest of that of the Dundee limestone.

The thickness of the Traverse in the district probably ranges from 125 to 175 feet, measurements at localities outside the district indicating that it is, like the other formations, thinner toward the south and thicker toward the north.

Character.—The most satisfactory section of the formation was obtained in the Pontiac well, just north of the Detroit district, and is as follows:

Section of Traverse formation in deep well at Pontiac.

	Feet.
Limestone, argillaceous, dark drab, coarse grained	25
Limestone, light drab, fine grained; 2 per cent insoluble residue	10
Limestone, light drab to grayish white; 8 per cent insoluble residue	7
Limestone, light gray; 20 per cent insoluble residue	8
Limestone, sandy, dark drab; 20 per cent insoluble residue	35
Limestone, argillaceous; 10 per cent insoluble residue	15
Clay, calcareous, light blue; 90 per cent insoluble residue	50
	150

The limestone strata are in many places so full of fossils as to be called "shell limestone" by the drillers, and the bluish calcareous shale is generally called by them "soap rock." Where such a stratum lies at the base of the formation, as in the section just given, its separation from the Dundee limestone is readily made. Where, however, the base of the Traverse is limestone, as is the case at Milan, just west of the Romulus quadrangle, the separation of the two formations is less satisfactorily made. The limestone of the Traverse, however, contains a large percentage of argillaceous matter and is typically of deeper blue color than the Dundee limestone.

Fossils and correlation.—The formation contains a rich and varied fauna, the fossils being well preserved and those in the soft shale being readily separated from the matrix. As the strata do not outcrop in the district the species are not enumerated here, but full lists are given in the publications of the Michigan Geological Survey.

The formation is of Middle Devonian age and closely related to the Hamilton of New York. Lane, basing his correlation largely on geologic position and lithologic similarity, considers the basal shale member as equivalent to the Marcellus shale of New York and the entire formation as the Michigan equivalent of the Erian of Clarke's classification. Grabau, who includes the Dundee limestone in his Traverse group, also refers the basal shale member of the Traverse to the horizon of the Marcellus shale of New York.

ANTRIM SHALE.

Definition.—The well-defined and readily recognized shale overlying the Devonian limestones in the central Lake region has been variously designated by the several State geological surveys. The name Antrim has been finally selected for use in Michigan because of the fine development and exposure of the formation in the Michigan county of that name. It comprises the beds between the uppermost bluish limestone or shale of the Traverse formation and the Berea sandstone.

Distribution and thickness.—As it is entirely covered in the Detroit district by surficial deposits, the distribution and thickness of the formation can be determined only approximately from the available well records, which are generally incomplete and to some extent contradictory. The formation crosses the northwest corner of the Romulus quadrangle and the middle of the Wayne quadrangle in a diagonal belt about

4 miles wide, which broadens eastward and occupies the north half of the Detroit quadrangle and nearly the whole of the Grosse Pointe quadrangle. Although many wells in the district enter the formation, not one of them furnishes a complete section of it, and the only knowledge of its thickness is obtained from the records of wells in the adjacent territory, which indicate a range in thickness from 160 to 275 feet, the thickness increasing, as in the older formations, toward the north and east.

Character.—The formation is made up of coal-black shale, which contains so much carbonaceous matter in many places that the rock may be burned and has been mistaken for coal. In places the shale is crisp, fissile, finely laminated, and very evenly bedded, and approaches slate in hardness. On weathering it assumes a gray or rusty-brown color from the oxidation of the iron minerals. Crystals of pyrite and nodules of marcasite are abundant and upon decomposition stain the shale with iron oxide and sulphur and impregnate the percolating water with the compounds of those elements.

Spherical to ellipsoidal calcareous concretions of considerable range in diameter are abundant in the shale. Toward their centers they contain crystals of calcite and siderite and not uncommonly fossils. The remarkable fossil fish of Ohio, described by Newberry, were obtained by Herzer from the concretions of this formation. When these concretions are encountered in borings they are likely to be reported as "limestone," and the larger nodules of pyrite and marcasite are often reported as "excessively hard." In this way a wrong impression is sometimes conveyed of the composition and character of the formation.

Much of the shale is impregnated with oil and when first penetrated by the drill it generally gives a flow of inflammable gas. Pockets of such natural gas are often encountered which give a high pressure temporarily and lead to false hopes concerning the quantity of gas. An analysis of a sample of the shale from Charlevoix County was made in order to test its possible fuel value, with the following results:

Analysis of Antrim shale.

[W. H. Johnson, analyst.]

Volatile matter	17.96
Fixed carbon	6.49
Ash	75.55
	100.00

Analysis of ash.

Silica (SiO_2)	70.54
Alumina (Al_2O_3)	15.33
Ferric oxide (Fe_2O_3)	5.31
Calcium oxide (CaO)	2.38
Magnesium oxide (MgO)	.78
Alkalies, etc., by difference	5.66
	100.00

The high carbonaceous content of the shale is due to the presence of immense numbers of minute disklike bodies with relatively thick walls. These were discovered by Dawson in the shale of Kettle Point, Ontario, and by Clarke in the Marcellus shale of New York, and are believed to be the fossil spores of floating plants. They have been described under the name of *Protosalvinia* (*Sporangites*) *huronensis* Dawson. During the accumulation of the shale conditions seem to have been unfavorable for the existence of the ordinary forms of vertebrate life.

Age and correlation.—Fossils suitable for correlation are so scarce that only the stratigraphic position and lithologic character of the formation are available for determining its age. As it resembles the Genesee shale of New York so strongly and overlies a formation of undoubted Hamilton age, it was long regarded as equivalent to the Genesee. Since the discovery by Grabau of a Naples fauna at its base, however, it is evident that it is younger than the Genesee and that its lower part is to be correlated with the Portage formation of New York.

CARBONIFEROUS SYSTEM.

MISSISSIPPIAN SERIES.

GENERAL CHARACTER.

Only the Mississippian series of the Carboniferous system is represented in the Detroit district. The strata consist of sandstone, shale, and a few thin beds of limestone, and are divided into two formations—the Berea sandstone below and the Coldwater shale above. Neither formation outcrops in the district, and only the lower part of the Coldwater shale underlies any of the area. Owing to their slight representation in the district, their lithologic similarity, and the meager information regarding them obtainable from a few well records, it seems best to treat these formations together.

BEREA SANDSTONE AND COLDWATER SHALE.

Definitions and distribution.—The basal formation of the Mississippian series is the Berea sandstone, a massive, coarse gray sandstone, generally contrasting strongly with the black Antrim shale upon which it rests. The next overlying formation, the Coldwater shale, named from the excellent exposures along Coldwater River in Branch and Hillsdale counties, Mich., is made up of light-colored thin-bedded shale and a few layers of limestone and sandstone. Large nodules of kidney iron ore are also met with and are often mistaken by drillers for limestone or sandstone. Toward the base the shale is black and forms a rather persistent member resting on the Berea sandstone. The upper part of the formation is sandy and in wells in areas northwest of the Wayne quadrangle it is separated from the overlying Marshall sandstone only with difficulty.

So far as can be learned from the meager data the two formations occupy the northwestern half of the Wayne quadrangle, the boundary between the Berea sandstone and the underlying Antrim shale cutting diagonally across the quadrangle from southwest to northeast. The greater part of the area underlain by the two formations is occupied by the Berea sandstone, only a few square miles of the northwest corner of the quadrangle being underlain by the lower part of the Coldwater. A deep well in Plymouth reached a gray shale (the Coldwater), 25 feet thick, at a depth of 100 feet, beneath which is sandstone and limestone. In another well, in the NW. ¼ SW. ¼ sec. 27, a thin flagstone, presumably the Berea, was entered for 6 inches, at a depth of 122.5 feet.

Thickness.—No data are available from which to determine the thickness of the formations in the Wayne quadrangle, but more complete records have been obtained in wells not far to the west and north. In the Campus well at Ann Arbor, Lane assigns 165 feet to the portion of the Coldwater shale present, of which the lowermost 45 feet seems to represent the Sunbury shale of Ohio. The upper part of the formation is not present at Ann Arbor and probably also does not occur in the Wayne quadrangle. Beneath is 15 feet of sandstone, assigned to the Berea and underlain by 115 feet of sandy shale, also probably part of the Berea, but not easily separated from the Antrim shale, and yielding salt water. In the Courthouse well at Ann Arbor, Rominger identified 92 feet of coarse, gray sandstone charged with brine as the Berea. The log of the deep well at Pontiac, just north of the Wayne quadrangle and 32 miles northeast of Ann Arbor, shows the Berea sandstone as 273 feet thick and overlain by 35 feet of dark shale assigned to the basal part of the Coldwater and probably equivalent to the Sunbury of Ohio. This indicates an average thickening northeastward of the Berea sandstone of 4 feet to the mile.

Correlation. — The two formations contain no fossils in southeastern Michigan, but their correlation with formations in Ohio on the basis of stratigraphic position and lithologic character is easy and reasonably certain, and the name Berea has been adopted from Ohio. In Ohio the Sunbury and Cuyahoga shales are regarded as separate formations, but in Michigan the two are combined as the Coldwater shale. The dark shale forming the lower part of the Coldwater is regarded as the equivalent of the Sunbury and the lighter sandy shale forming the upper part as the equivalent of the Cuyahoga and possibly also of a part of the Black Hand formation of Ohio.

QUATERNARY SYSTEM.

GENERAL CHARACTER.

The blanket of surficial deposits that covers the bedrock throughout nearly the whole district consists for the most part of glacial drift and lacustrine deposits of Pleistocene age but includes some alluvium and lacustrine deposits of Recent age.

The glacial drift, which, although the source of nearly all the material that forms the lacustrine and alluvial deposits, itself occupies only between 3 and 4 per cent of the surface of the district, is almost wholly of Wisconsin age, and only material of that age is exposed at the surface. Till of presumably Illinoian age and interglacial deposits of possibly Sangamon age have been encountered in a few borings and excavations. The iWsconsin drift includes the till of the ground moraine or general till sheet, the till that forms a series of recessional terminal moraines, and the stratified sand and gravel that is either interbedded with the till or deposited on it.

The Pleistocene lacustrine deposits, which occupy about three-fifths of the surface of the district, were formed in a series of glacial lakes—the predecessors, in late Wisconsin time, of the present Great Lakes. The deposits include beds of perfectly stratified clay laid down in the quieter parts of the glacial lakes, delta deposits formed at the mouths of rivers that flowed into the lakes, and beaches and associated dunes formed about their shores.

The Recent deposits, which make up only a small part of the Quaternary deposits of the district, include alluvium, which has accumulated along the courses of the larger streams and in swamps and kettle holes, and delta deposits, beach sands, and dune sands formed about the shores of Lake Erie and Lake St. Clair. Deposits like these are still being formed.

PLEISTOCENE SERIES.

ILLINOIAN (?) DRIFT.

A layer of indurated till lies on the bedrock beneath the Wisconsin drift in several places in the district, as in the pit of the American Silica Co., near Rockwood, where it is 14 to 16 feet thick and very hard, though only its lower part is exceptionally stony. In the bed of Lake Erie near the Detroit River Light uncommonly hard till was encountered in dredging, and similar hard, stony, rusted till was found in the bed of the Livingstone channel of Detroit River. (See Pl. V.) The surfaces of pebbles from this deposit are so much etched by solution that the delicate scratches characteristic of pebbles from the Wisconsin drift are largely obliterated. Well drillers often report that the bedrock is overlain by "hardpan," which may be this old, indurated till. It was not recognized, however, in either of the two salt shafts in the district nor in the test borings made for the Detroit tunnel. Till that is regarded as of Illinoian age has been found at several places in the adjoining Ann Arbor quadrangle, so the old, indurated till about Detroit may also be of Illinoian age.

INTERGLACIAL DEPOSITS.

Some well records show that a thin layer of soil or compacted peat is embedded in the drift, but such records are always meager and unsatisfactory. The thickest deposit of this sort was reported from a well drilled near the center of sec. 30, Erin Township, Macomb County, where, at a depth of 85 feet, the drill passed through 17 feet of loose carbonaceous soil lying on 23 feet of firm clay, which in turn lies on bedrock. These layers of soil are presumed to be of Sangamon age, but the evidence at hand is too meager to permit their definite correlation.

WISCONSIN DRIFT.

GLACIAL DEPOSITS.

General Till Sheet.

Distribution and thickness.—The Wisconsin till sheet covers the entire district except a few small outcrops of bedrock. In nearly every exposure the bottom is seen to rest directly upon bedrock, but at a few places it rests upon older Pleistocene deposits, and in most of the district it is itself covered by lacustrine and alluvial material. Its thickness is probably 250 feet in Royal Oak Township and near the higher moraines. It is thinnest near the mouth of Detroit River and thickens gradually toward the west and more rapidly toward the northwest and north. As left by the ice its surface was smooth and sloped gently southeastward. Local hollows in the bedrock surface allowed more extensive accumulation in certain areas, as in eastern Van Buren, southeastern Nankin, northeastern Dearborn, and the southern parts of Hamtramck, Gratiot, and Grosse Pointe townships, where the Wisconsin till sheet is 160 to 180 feet thick. The general effect of the deposition of the sheet was thus to reduce the relief of the greater part of the area.

Character.—The Wisconsin till is characteristically soft and fresh, except when it is dried. Under its own weight, and especially if wet and subjected to additional pressure, a mass of it will creep and flow. Except close to bedrock it contains few pebbles (see Pl. VI) and only here and there a cobble or bowlder. Most of its stony material is subangular, generally striated, and consists largely of dolomite, limestone, chert, and argillite, only about 10 per cent of the whole consisting of quartzite and other crystalline rocks.

The till contains lenticular masses of gravel and sand, many of them "quicksand" filled with water and ready to flow whenever the pressure on one side is relieved, as in excavations. The instability of these sands and of the till itself is a source of danger to many forms of construction.

Although generally without identifiable structure, the Wisconsin till in places, as on the dried face of the exposed stripping about the Sibley quarry, shows horizontal lamination or cleavage, due presumably to the great weight of the ice. None of the sections studied showed a horizon of demarcation between early and late Wisconsin till or a soil of intra-Wisconsin age.

Weathering and erosion.—The upper part of the till is considerably weathered, the iron compounds being rusted to a depth of 20 to 25 feet, though the calcium carbonate is ordinarily leached only for 6 to 18 inches, to depths at which there is a concentration of the carbonate and iron oxide. The amount of rusted till beneath Detroit River is small. At many places near Detroit the brownish till is colored bright blue along joints to a depth of one-tenth of an inch on each side of the joint plane, as if water percolating along the joints had carried some deoxidizing agent which restored the original color of the till. The pebbles in the Wisconsin till show but little effect of weathering; even the pebbles of limestone and dolomite preserve the most delicate scratches, presenting a striking contrast to similar pebbles from the Illinoian (?) till.

The streams have cut valleys in the Wisconsin till to a maximum depth of 50 feet and a maximum width of two-thirds of a mile. Nevertheless Leverett has estimated that in about nine-tenths of the area the original surface of the Wisconsin till has not been disturbed.

Moraines.

General character. — Parts of five recessional terminal moraines, two of them double, have been mapped in the northern and eastern parts of the district, the Romulus quadrangle being practically outside the region of moraine deposition. These moraines are members of a larger series formed in succession about the margin of the Huron-Erie lobe of the late Wisconsin ice sheet during its disappearance from southeastern Michigan. Owing to changes in the position and trend of the ice margin at the time of the formation of the moraines their trend ranges from northeast to northwest. (See fig. 7.)

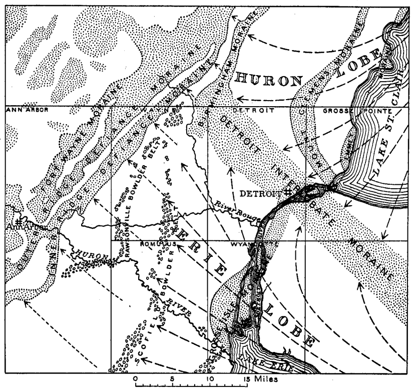


FIGURE 7.—Map of the moraines in the Detroit district and adjacent region, showing by arrows the direction of movement of the Erie and Huron ice lobes during the formation of these moraines.

The Fort Wayne and Defiance moraines were formed on land by the united Huron-Erie lobe, which at this stage moved northwestward, as indicated by lighter arrows. The Birmingham moraine, deposited in part on land and in part in the waters of glacial Lake Maumee, and the Mount Clemens moraine, deposited in Lake Maumee, were formed by the Huron lobe after it had separated somewhat from the Erie lobe. The Scofield bowlder belt marks the position of the ice front of the Erie lobe at the time the Birmingham moraine was formed, the Erie glacier not being active enough to produce a typical moraine. The Detroit moraine was formed under the ice along the junction of the two lobes at the same time that the Birmingham moraine was being formed, and the directions of movement of the ice lobes are shown by heavier arrows. The Emmet and Grosse Isle moraines were deposited in Lake Maumee by the ice after it had readvanced over the ends of the Mount Clemens and Detroit moraines and the two lobes had temporarily reunited.

Three types of moraines are represented—the prominent, rough moraine deposited on land; the subdued, regular moraine deposited in water; and the inconspicuous, subglacial moraine, which is nothing more than a broad swell in the general surface of the till sheet. They are formed mainly of bluish till, horizontally laminated in places, and contain a sprinkling of cobbles and bowlders (see Pl. VI), which are mostly quartzite and other crystalline rocks foreign to the district and are only rarely striated, apparently having been carried upon or within the ice. Two of the moraines that were deposited in water appear to be continued as bowlder belts across the district and into Ohio, where they apparently mark the approximate positions of the ice margin at places in which conditions were not favorable for the formation of a definite moraine.

Defiance moraine. — The Defiance moraine, named from Defiance, Ohio, is regarded by Leverett as double in this district and in the adjacent part of the Ann Arbor quadrangle. The older and more western member has been called "Middle moraine" and "Northville moraine" but is here mapped as the outer ridge of the Defiance moraine. It is separated from the inner ridge by the valley of the ancient stream which flowed southwestward across Farmington, Novi, and Northville townships. (See Pl. IV.)

The moraine extends southwestward across the northwest corner of the Wayne quadrangle, forming a belt, 3 to 4 miles wide, which includes the highest and roughest part of the entire district. The till ridges and mounds, most of which have steep slopes and attain altitudes of 940 to 960 feet above sea level, have no regular arrangement and are interspersed with numerous kames. The inner ridge is not so high as the outer, the summits rising generally to altitudes of 840 to 860 feet. The eastern side of the moraine is steeper than the western side and is dissected by short parallel streams.

Birmingham moraine.—This moraine, named from Birmingham, in Oakland County, lies mainly north of the Detroit district and was formed chiefly on land. Its southwest end, however, which was laid down in the water of glacial Lake Maumee, extends about 4 miles into the Wayne quadrangle. It trends southwestward across the town of Southfield and descends from 700 feet above sea level to 640 feet, where it merges into the general lacustrine deposit.

Although much of the surface of this southern part of the moraine is strewn with sand and gravel, which obscure the morainic features, nevertheless the moraine determined the position and trend of the beaches in this part of the district and deflected Rouge River southwestward from what would otherwise have been its natural course. The moraine disappears as a topographic feature in the northeast corner of Livonia Township, but a bowlder belt which appears to be a prolongation of it extends south across the quadrangle and into Ohio.

Detroit interlobate moraine.—A broad drift swell which extends from the neighborhood of Birmingham southeastward across Southfield, Royal Oak, Redford, and Greenfield townships, has been called the Detroit interlobate moraine. As a topographic feature it is inconspicuous and almost unrecognizable, yet it controls the drainage, and its position is indicated by the course of the beach ridges and by the contours on the topographic map. From a breadth of 7 or 8 miles at the north it gradually narrows toward Detroit River and descends from an altitude of 700 feet to that of the river, by which it has been partly destroyed. Its course across Essex County, Ontario, toward Leamington can be readily traced. Taylor and Leverett believe that it was formed subglacially along the line of junction of the Huron and the Erie ice lobes and was contemporaneous with the Birmingham moraine, deposited along the outer edge of the lobes. It is thus referred to as a "subglacial interlobate moraine," this origin accounting for its course, position, subdued character, and scarcity of bowlders.

Mount Clemens moraine.—Lying just east of the Detroit interlobate moraine and extending directly northward from Detroit through Hamtramck and Warren townships is a poorly defined frontal moraine, of the kind deposited in water, called by Taylor the Mount Clemens moraine, from its relation to the city of that name. It was deposited in the waters of glacial Lake Maumee. It contains a sprinkling of cobbles and bowlders and is better defined at the north, where it was deposited on land by the Huron ice lobe. Theoretically there must have been a deposit formed at the same time, south of the Detroit moraine, by the Erie lobe, but no such moraine has been identified and it may have been overridden and destroyed by a subsequent ice advance.

Emmet and Grosse Isle moraines.—Two moraines bordering Lake St. Clair and Detroit River consist of parallel and, in places, remarkably regular, gentle till ridges having abundant cobbles and bowlders on their surfaces. They lie mainly between 580 and 600 feet above the sea and are not well shown on the topographic maps. From the crest of the Detroit moraine northeast to Milk River Point an included strip of younger moraine is regarded by Taylor as part of the Emmet moraine. The "Grosse Pointe" of the early French settlers, as well as Milk River Point, owes its existence to this moraine, the concentration of bowlders on its east side by waves having saved it from destruction. (See Pl. VII.) The chart of Lake St. Clair shows that a stony-clay ridge, apparently the northward continuation of this moraine, extends for 3 or 4 miles beyond Milk River Point beneath the western part of the lake. The moraine may be traced into Detroit, where a regular series of seven till ridges lies on the eastern slope of the Detroit moraine, just north of Elmwood Cemetery, between Hunt and Willis streets, spaced almost exactly two blocks apart and dying out to the east and west. Similar ridges are found near the waterworks and on the west side of Belle Isle. Some geologists regard these till ridges as remnants of the Detroit moraine between scoured channels of distributaries of Detroit River. This view, however, appears to the author untenable, for these troughs run up the slope and lie at markedly different levels. The ridges were evidently built up as they now are, and the intervening troughs are not valleys of erosion.

Other ridges lie on the crest of the Detroit moraine, both in Detroit and Windsor, showing that it was overridden by the ice, and may be traced southward along the river, except where they were destroyed by the waters of Lake Rouge, as far as the mouth of Huron River.

These morainic ridges are well developed also on Grosse Isle, in view of which fact the author has suggested the name Grosse Isle moraine. The moraine has a trend of N. 35°–40° E. and a breadth of 8 or 9 miles. Toward Huron River the ridges die out, and across Monroe County the moraine appears to be represented only by a bowlder belt. Between Wyandotte Heights and Detroit the moraine lies mainly in Ontario, crossing the river at Stony Island and causing the accumulation of bowlders at Limekiln Crossing (see Pl. VIII), which, in conjunction with an anticline in the bedrock, has been such an obstruction to navigation at that point. The islands in the river are part of the moraine and where the moraine lies east of the river there are no islands.

Bowlder Belts.

Rawsonville bowlder belt.—Several belts of bowlders, which cross the district from northeast to southwest, are believed by the author to mark positions of halt of the retreating ice front, unaccompanied by much deposition of till. The westernmost belt, here called the Rawsonville, is rather closely associated with the Defiance moraine. It may be traced continuously southwestward from Farmington across the northwest corner of Livonia and the eastern part of Plymouth townships and thence southward across the center of Canton and Van Buren townships to Belleville, where its course is obscured, but it appears to turn west and to cross Huron River at Rawsonville, where there is a considerable concentration of bowlders. The belt continues westward into Washtenaw County and appears to join the Defiance moraine in the southwest corner of Ypsilanti Township. In Livonia and Plymouth townships it lies between 700 and 720 feet above sea level, descending in Canton Township to between 700 and 680 feet, and rising to its former altitude as it enters Washtenaw County.

Scofield bowlder belt.—A second bowlder belt, which has been traced across Wayne, Monroe, and Lenawee counties into Ohio, has been named the Scofield bowlder belt. The bowlders are subangular, fairly abundant, and are chiefly granite, gneiss, schist, greenstone, conglomerate, and quartzite; limestone, sandstone, and argillite are rare. The belt is a mile or two wide and is not well defined in Oakland and northern Wayne counties but is better defined to the south. In places it is obscured by sand and gravel. It passes southward across Livonia and Nankin townships and shows a slight suggestion of morainic topography in sec. 15 of Livonia Township. In northern Romulus Township bowlders are abundant, but the belt is obscured by sand toward the southwest. It appears again in Huron and Exeter townships and may be traced into Ohio. In crossing Wayne and Monroe counties it descends from 680 to 620 feet above sea level and then rises to higher ground in Monroe and Lenawee counties. As previously noted, this belt seems to be the continuation of the Birmingham moraine, although possibly it extends directly northward to Farmington and there joins the Defiance moraine. However, inasmuch as the retreat of the margin of the Erie ice lobe must have been interrupted while the Birmingham moraine was being formed, it seems probable that the Scofield bowlder belt was formed at the same time.

Grosse Isle bowlder belt.—As the Grosse Isle moraine is traced south toward Huron River, the parallel ridges become more obscure and eventually die out, but a belt, 1 to 2 miles wide, of bowlders and cobbles continues across Monroe County into Ohio, where it curves southward and is parallel to the Scofield bowlder belt. There can be little question that this belt marks the approximate position of the ice front while the Grosse Isle moraine was being deposited.

Kames

Associated with the Defiance moraine and interspersed among the till ridges and knobs of both the inner and the outer members are numerous circular to elliptical hills of sand and gravel, generally with steep slopes, which give rise to the strongest relief in the morainic belt. They are particularly numerous in an area 2 to 3 miles wide, near Northville. A prominent kame, rising 100 feet above the valley floor and more than 900 feet above sea level, stands just east of the village. (See Pl. X.) It has supplied large quantities of gravel for the Detroit United Railway Co., and a good section of the kame is exposed in the gravel pit. It is made up largely of stratified and in many places cross-bedded sand and gravel, the pebbles of which are subangular to rounded and consist mainly of limestone, dolomite, and chert. In this respect they are similar to the pebbles found in the till and contrast sharply with the stony material strewn over the surface of the moraines and making the bowlder belts.

A row of five kames disposed in a northeast-southwest course, one of which has a capping of till (see Pl. IX), lies about a mile west and northwest of Farmington. A small kame stands just south of Novi, and other small kames are about 2 miles northwest and northeast of the same village.

The Defiance moraine is the only one in the district having kames associated with it. The other moraines were deposited in water or beneath the ice, and the conditions were unfavorable for the formation of kames.

Outwash Gravel.

A deposit of gravel and sand, more than 8 miles in length, from half a mile to a mile in width, and of unknown thickness, forms the floor of the valley of the stream that flowed from the ice sheet while the inner ridge of the Defiance moraine was being formed. The general trend of the deposit is from northeast to southwest across Farmington, Novi, and Northville townships, and it continues in both directions outside the Wayne quadrangle. Its surface along the northern side is about 860 feet above sea level and descends toward Northville at an average rate of 10 feet to the mile.

LACUSTRINE DEPOSITS.

Sand, clay, loam, and gravel deposited in glacial lakes and along their shores cover the larger part of the district, practically forming the surface of all the area southeast of the Defiance moraine. These deposits are mainly clay, loam, and sand, laid down in the deeper, quieter parts of the lakes. These are crossed by delta sands and linear ridges of beach sand, which mark the shores of the several stages of the lakes. The names of these beaches and their elevations and sequence are shown in figure 9 (p. 15).

Deposits of Lake Maumee.

Beaches.—Three beach ridges, from an eighth to a quarter of a mile apart, which pursue rather tortuous and broken courses along the eastern slope of the inner ridge of the Defiance moraine, mark successive stages in the level of glacial Lake Maumee. Owing to the manner and time of its formation, the middle beach is the best defined and the lowest is the least so. The general trend of the beaches is from northeast to southwest, but they follow the irregularities of the moraine and here and there have been obliterated by stream erosion. In a few places their positions are indicated by benches instead of ridges. Continuous tracing of the separate beaches is difficult, and identifiable fragments can be pieced together only with the help of the topographic maps. The beaches extend many miles outside the area and the two higher have been called Van Wert and Leipsic, from the names of small villages in Ohio.

In the Wayne quadrangle the crests of these beaches are level, in contrast with parts of the same beaches in the area north of the Detroit district. They furnish local supplies of sand and gravel and some wells are located on them, and therefore small sections are here and there exposed for study. They consist of cross-bedded sand and gravel ranging in thickness from a few inches to 18 feet. Examination shows that the pebbles in the gravel were derived from the till, but that dolomite, limestone, and argillite pebbles are slightly less abundant and pebbles of quartzite and other crystalline rocks are slightly more abundant than in the till. All three beaches are well developed, close together, and easily accessible for study along the road between sec. 12 of Northville and sec. 7 of Livonia townships.

The highest beach lies 812 feet above sea level. It enters the Wayne quadrangle 2 miles west of Plymouth and, where cut by the Pere Marquette Railroad, is 200 feet wide and rises 4 feet above the general slope of the moraine. With interruptions it may be traced northeastward across the southeast corner of Northville and the northwest corner of Livonia townships to where it enters Farmington Township in sec. 31. In the irregular embayments just west and north of Farmington no well-defined ridge was formed, but considerable sand was deposited in the shallow water. This beach was formed during a single stage of a relatively small lake, whose outline conformed to the irregular contour of the moraine and which accomplished little in the way of modifying its shore line.

The middle or main Maumee beach lies between 785 and 795 feet above sea level, or about 25 feet lower than the upper one. It is better defined than that beach and forms a more conspicuous topographic feature, parallel to and just east of it. Where the slope is steep the two are only 500 to 600 feet apart. Although consisting mainly of gravel, or gravel and sand, in places the ridge consists very largely of sand, especially near Farmington, where the beach cuts through the western edge of the village. In the NW. ¼ sec. 13, Farmington Township, the beach is especially well defined on the slope of a spur of the moraine. It is so well developed at numerous other places along its course that it has sometimes been mistaken for the Whittlesey beach, which lies considerably lower and a mile to the east.

Fragments of a beach marking a still lower stage of Lake Maumee are found at 760 to 770 feet above sea level. It is best defined opposite the mouths of the streams, apparently because of the material supplied for building deltas at those points. Such a sandy gravel ridge lies just west of Plymouth, in the NE. ¼ sec. 27 and the SE. ¼ sec. 22, Plymouth Township. The beach is fairly well developed in the SE. ¼ sec. 12, Northville Township, and across the center of sec. 13, Farmington Township. Throughout most of its course it is rather poorly developed and has the appearance of having been submerged after its formation. It is believed to have been formed next after the upper beach and then to have been submerged while the middle beach was being formed.

Delta deposits.—Thin deposits of sand and loam, somewhat pebbly in places, were formed as deltas at the places where the predecessors of the middle and upper branches of River Rouge and their tributaries emptied into the successive stages of Lake Maumee. A small amount of such material is found between Plymouth and Waterford and still more of it southwest, west, and north of Farmington, where much of it was subsequently worked over and redistributed by the waves. The deposit near Plymouth is mainly loam and covers about a square mile, and the Farmington area comprises about a square mile of sand and 2 square miles of loam. Both areas were probably originally larger and both probably extend southeastward under the younger lacustrine deposits. Data are lacking from which to determine the average or maximum thickness of these delta deposits, but they probably constitute only a thin veneer of stratified sand or loam resting on the gentle slope of the Defiance moraine. The bulk of the deposit is apparently referable to the middle stage of the lake, the latest in point of time.

Deposits of Lake Arkona.

Beaches.—Next in order of age, though not in position, are three roughly parallel low sand ridges at approximate altitudes of 710, 700, and 695 feet above sea level, marking corresponding stages of glacial Lake Arkona. They lie 2 to 3 miles southeast of the Maumee beaches and have the same northeast-southwest trend. Across the Arkona deltas the beaches form rather symmetrical curves, convex southeastward. This feature is best displayed near Plymouth and Southfield and not so well near Farmington. In some places the sand seems to have been blown or washed away and only the few pebbles left on the clay mark the position of the beach. In other places lake sediments appear to have obscured the small amount of beach deposit, but where deltas were being formed, as at the mouths of the tributaries of River Rouge, much larger ridges were built and have persisted.

At Denton, just west of the district, the ridges are close together and contain considerable sand. The lower beach is well represented in the NW. ¼ sec. 1, Canton Township, by a gravel ridge 900 feet across, 4 to 5 feet above the general surface, and 696 feet above sea level. East of Plymouth the profile of the Pere Marquette Railroad gives a section of the Arkona beaches that were built upon the delta of Middle River Rouge. A broad swell, 2,600 feet across and 5 feet above the general level and carrying several minor ridges, extends from sec. 24 into sec. 25, Plymouth Township. The railroad altitude shown is 713 feet, a little higher than the uppermost Arkona beach, but there may be a slight error in the leveling. About 4,000 feet to the east another 700-foot crest crowns a broad swell 2,000 feet across and 6 to 8 feet above the general level. These broad sand swells indicate in a general way the position of the shore line, which has been located only approximately along their crests. In sec. 30, Livonia Township, ridges are shown with altitudes of 695, 689, and 683 feet, the lowest evidently being the Warren beach. A well-developed strip of the lowest Arkona beach lies about a mile northwest of Southfield and extends eastward across the southern part of sec. 17. Just west, in sec. 18, the highest Arkona beach is well developed, but the middle beach is not there recognized.

Deltas.—The largest deltas of the entire series of lakes are associated with the various stages of Lake Arkona, although they can not be entirely differentiated from similar deposits of Lakes Whittlesey and Warren. They consist of pebbly sand and loam, interbedded with thin sheets of gravel, and cover nearly 30 square miles of the Wayne quadrangle, mainly in Plymouth, Livonia, Farmington, and Southfield townships. The best-developed delta is in southeastern Plymouth and southwestern Livonia and forms a flat, fan-shaped deposit, 12 to 15 feet thick and resting on clay. Measured radially the deposit extends 2½ to 3½ miles from the mouth of the Middle Rouge of that time, and its surface slopes from 12 to 20 feet to the mile. Toward the margin the pebbles are smaller and less numerous and the delta sand grades into the ordinary lake sand and loam.

During the same stage of the lake a similar but larger delta in southwestern Wayne County and the adjacent part of Washtenaw County was formed by Huron River. It lies mainly just west of the Romulus quadrangle, in Van Buren and Sumpter townships, but, together with the deposits of lakes Whittlesey and Warren, it covers nearly 20 square miles of those townships in the quadrangle. In this part the surface slope is only 6 or 7 feet to the mile. The deposit is 20 feet thick in the western part of Van Buren, thins gradually eastward, and gives out as the present valley is reached. The part lying west, south, and east of Belleville is more loamy, apparently due to younger deposits.

Deposits of Lake Whittlesey.

Beach.—The Whittlesey beach lies between the lowest Maumee and the highest Arkona beaches and has the same northeast-southwest trend. It crosses Plymouth, Northville, Livonia, Farmington, and Southfield townships in a nearly direct line. It is the most conspicuous beach ridge in the district, being 300 to 900 feet across and standing 7 to 15 feet above the general level of the lake plain. In many places it deflects the drainage, determines the location of highways, and furnishes attractive building sites. It was generally recognized by the pioneers as an old shore line and it received early attention from the Michigan and Ohio geological surveys. Bela Hubbard traced it across southeastern Michigan for 60 miles, and it was approximately located on the map of Wayne County prepared by Higgins and published in 1840.

The beach enters the Wayne quadrangle near the center of sec. 33, Plymouth Township, passes directly through Plymouth, and determines the location and direction of the main street. Just after crossing the Middle Rouge it makes a slight curve and then holds a remarkably direct course through Farmington, leaving the quadrangle in the NW. ¼ sec. 18, Southfield Township. The altitude of its crest ranges from 735 to 740 feet above sea level and from 162 to 167 feet above Lake Erie. In the Detroit district no effect is discernible of the differential uplift which sets in just to the north. The western or landward side of the beach is perceptibly steeper than the eastern or lakeward side. For some distance along the eastern side, particularly in Livonia and Farmington townships, cobbles and some bowlders have been concentrated at the surface of the till by wave action.

Well records indicate that the beach deposit is 10 to 25 feet thick. As seen in sections exposed in gravel pits it consists of interstratified and cross-bedded sand and gravel. (See Pl. XII.) The pebbles are well rounded and of about the same character as those of the Maumee beaches.

Spits or bars.—A pair of spits or gravel bars branch off from the Whittlesey beach just east of the Middle Rouge, at Plymouth. The easternmost or inner one is simply a continuation of the main beach southward for seven-eighths of a mile, from sec. 24 across the northwest corner of sec. 25, Plymouth Township; the crest descends gradually until the ridge merges with the general surface of the delta upon which it rests. The main beach in the SW. ¼ sec. 24 curves rather abruptly westward, and between it and the spit just described is a second less well-defined ridge about half a mile long. The diagonal highway in sec. 24 which runs on the crest of the Whittlesey beach is continued along the crest of the main spit for nearly its entire length. Where crossed by the Pere Marquette Railroad its altitude is 726 feet, this part being barely awash at the time of its formation. The following section was exposed there in 1902:

Section of Whittlesey beach deposit near Plymouth.

	Ft.	in.
Loam, yellow, gravelly	1	0
Gravel, fine, stratified, dipping westward	1	3
Sand, stratified horizontally	1	3
Sand and gravel, cross-bedded (bottom of deposit not exposed)	20	0

Deltas.—The only stream discharging into Lake Whittlesey, in the Wayne and Romulus quadrangles, that was at all active in depositing detritus was the Middle Rouge. In the slight depression between the Whittlesey beach and the highest Arkona beach the surface is covered with pebbly loam resting upon sand and gravel, which occupy 3 square miles in eastern and southern Plymouth Township and rest in turn on the ground moraine. Some of the finer material was carried 2 or 3 miles along shore by waves and currents and must have extended out over the Arkona delta, which at that stage was completely submerged. The general slope of the surface of the deposit is 8 to 12 feet to the mile.

Deposits of Lake Wayne.

Beach.—The deposits of Lake Wayne come next to those of Lake Whittlesey in order of age, but not in position, as the surface of the lake was considerably lower than that of Lake Whittlesey and, in the subsequent Lake Warren stage, the water rose again nearly to the level of Lake Arkona and the Wayne beach was submerged. In contrast with the Maumee, Whittlesey, and Warren beaches that of Lake Wayne, although here and there pebbly, is composed almost entirely of sand. As a result of its having been modified by later action of wind and wave, the tracing of the exact position of the strand line is rather difficult in many places. In the vicinity of Wayne, from which village the lake and beach derive their name, the beach consists of a broad, flat swell of sand 3,400 feet across, 5 feet above the general surface, and 655 feet above sea level. Where best defined its crest appears to lie between 650 and 660 feet, but bars were formed at lower levels in the shallow water in front of the beach, and the wind here and there heaped the dry sand into dunes, the tops of some of which have greater altitudes than can be assigned to the beach proper.

The Wayne beach enters the Romulus quadrangle in the NW. ¼ sec. 28, Sumpter Township, and extends northeastward past Martinsville, Romulus, Wayne, Livonia, Clarenceville, and Royal Oak. In Nankin Township and the southern half of Livonia Township its trend is northerly, but it swings eastward and southeastward in Southfield and Greenfield townships, to pass around the Detroit moraine, and then curves, with considerable interruption, sharply to the north again across the center of Royal Oak Township. Behind the Detroit moraine, in the northeastern part of Livonia Township, the beach is poorly developed and traceable with difficulty, but on the lakeward side of the moraine, in Greenfield and Royal Oak townships, it is prominent, and in Royal Oak Township it is double for 3 miles and contains many small pebbles.

Shore deposits.—In front of the Wayne beach, throughout nearly its entire length, a thin dressing of sand, somewhat pebbly in places, mantles the lacustrine and glacial clays. The belt is of irregular width, but nearly everywhere it extends from 1 to 3 miles down the slope to the Grassmere beach, where it mingles with similar material deposited in glacial Lake Lundy. The continuity of the belt is interrupted only in southern Livonia Township and there only for a short distance. The deposit thins gradually eastward and southeastward and merges into the beach deposit in the opposite direction. It represents in part fine delta material more or less reworked by the waves and in part similar material derived directly from the till by wave action.

An interesting series of sand spits and bars, most of them roughly parallel to the main beach ridge, is developed on the crest and eastern slope of the Detroit moraine in northern Greenfield and southern Royal Oak. They consist of narrow sand ridges of about the same height as the beach itself and are spaced from a quarter to half a mile apart. They range in length from a quarter of a mile to 3 miles. The spits are best developed just over the crest of the moraine in secs. 20, 21, 22, 15, and 16 of Greenfield Township. Just west of Palmer Park, in secs. 9 and 10 especially, the ridges are shorter and less regularly placed and some at approximately right angles to the beach are apparently bars.

Deposits of Lake Warren.

Beach.—The Warren beach, formerly known as the Upper Forest beach, although younger than the Wayne beach, lies considerably higher, next to the lowest Arkona beach, to which it is roughly parallel. It is rather poorly represented in the Romulus quadrangle, but assumes definiteness and character in places in the Wayne quadrangle. It is composed more largely of gravel than the Wayne beach and in places it resembles the Whittlesey beach although it is not so high and broad. The crest is nearly everywhere 682 feet above sea level and shows no indication, in the Detroit area, of the differential uplift that sets in just to the north.

The beach enters the Romulus quadrangle in sec. 4, Sumpter Township, swings to the west in a smooth curve through sec. 33, Van Buren Township, and leaves the district to reenter it north of Huron River. Northeast of Belleville the beach consists of a rather well-defined pebbly ridge of sand and two short bars at a slightly lower level. Thence its course is northward across Van Buren and Canton townships, a well-defined gravel ridge a mile and a half long passing through Canton village. For the next 6 miles there is very scant trace of beach or shore line, but across the Arkona delta of the Middle Rouge, in the southwest corner of Livonia Township, a well-defined pebbly ridge of sand was formed in the SE. ¼ sec. 31. In the northeast turn of the beach a similar but longer pebbly ridge was formed across sec. 9 of the same township. Little beach is now left behind the Detroit moraine in Farmington and Southfield townships, but across the crest of the moraine in secs. 25 and 24, Southfield Township, and secs. 19 and 18, Royal Oak Township, gravelly sand ridges, about half a mile east of the lowest Arkona beach, mark the Warren shore line.

Bars and deltas.—Gravel and sand ridges, with crests somewhat below that of the main Warren beach but higher than the Wayne beach, occur at several points in the district at intervals of a mile or two. They are from half a mile to a mile and a half long, more or less curved, and evidently bars. The longest and simplest trends northwest and southeast across secs. 35 and 36 of Southfield Township. A prominent semicircular gravel-sand ridge, with a short curved spur on the southern or concave side, lies in the SE. ¼ sec. 12, Van Buren Township. Where the beach approaches the Huron Valley, 2 miles to the southwest, are two closely placed crescentic bars convex toward the southeast or lake side.

The delta deposits formed by Huron and Middle Rouge rivers in Lake Warren can not be fully differentiated from those of Lake Arkona. They form a veneer of pebbly sand at the former mouths of the streams and between Warren and Wayne beaches. The level delta terrace of gravelly loam on which Belleville is built covers about 8 square miles, stands about 680 feet above sea level, and is evidently to be referred to the Lake Warren stage. A section in the village shows 5 feet of yellow loam and gravel, resting on till. The upper branch of the Rouge accomplished but little in the way of delta formation, at the Warren stage, but in southeastern Farmington it deposited some loam and pebbly sand between Farmington Junction and Clarenceville. A small but well-defined delta, extending southwestward from Southfield back of the Birmingham moraine and composed of gravel, sand, and silt, covers about a square mile.

Deposits of Lake Lundy.

General character.—Two series of disconnected sand deposits, having a general northeasterly trend across the district, mark two stages of the glacial lake named Lake Lundy by F. B. Taylor from a beach in the Niagara region, described and named by J. W. Spencer. Neither shore line can be traced continuously, and the beach ridges are much confused with dunes on one side and bars and spits on the other. The two beaches, known as the Grassmere beach and the Elkton beach, are 4 to 7 miles apart, except near the steeper slope of the Detroit moraine and in northwestern Springwells Township, where they are not more than a mile apart. In the Detroit district their difference in altitude is only 20 to 25 feet, instead of 75 to 80 feet, as in Huron County. In general character they resemble the Wayne beach, and the dunes on the landward side of the Grassmere beach and the bars on the lakeward side of the Wayne beach, as well as the commingling of the lacustrine sand that was deposited along the front of the Wayne beach for 2 or 3 miles and the eolian sand blown landward from the Grassmere beach, connect the deposits of the two lakes and make separation difficult.

The deposits made by the streams that flowed into Lake Lundy consist largely of sand that appears to have been reworked by the waves and not left in typical deltas. Local deposits of finely laminated clay were laid down on the lake bed, but undoubtedly the deposition of clay had already begun during the existence of the earlier lakes.

Grassmere beach.—The crest of the higher beach, named Grassmere by Lane from a village in Huron County, Mich., is approximately 635 feet above sea level in the Detroit district, but some of the associated dunes rise 12 to 18 feet higher. The southernmost deposit assigned to the Grassmere beach in this district is in southern Sumpter Township. From Exeter it extends northeastward, and for 10 miles it consists of a series of disconnected ridges, mostly short but some of them 2 miles long. The longer ones are nearly parallel to what must have been the shore line, but many of the shorter ones are inclined to that line or even at right angles to it.

At Romulus the beach and associated ridges swing northeastward and thence northward, crossing Nankin Township just east of its center. In Livonia Township a long, well-defined ridge assumes form in sec. 27 and branches in the SE. ¼ sec. 22, one branch extending northward for a mile, the other curving abruptly eastward for 2 miles through the southern half of secs. 23 and 24. At Sand Hill, Redford Township, two prominent sand ridges, apparently formed by the wind, rise to heights of 640 and 660 feet. Around the peninsula made by the Detroit moraine a number of ridges were formed, much as in the case of the Wayne beach. Sand ridges containing some gravel stand both north and south of Grand River Avenue in secs. 28, 29, and 30 of Greenfield Township. The eastern half of the township, near Highland Park and Palmer Park, is spotted with beach and bar ridges. The somewhat prominent sand ridge that crosses Woodward Avenue about the center of Highland Park village is one of the longer strips of the Grassmere beach. Shorter and irregularly placed sand ridges, surrounded by eolian and lacustrine sand and marking the same stage, are found in southeastern Royal Oak and western Warren townships.

Elkton beach.—The lower Lundy or Elkton beach was also named by Lane from a village in Huron County, Mich. Across the Detroit district it is a single, discontinuous sand ridge, whose crest is 610 to 615 feet above sea level and which is correlated by Taylor with the Lundy beach of Ontario and western New York. In western Ash and southwestern Huron townships and near Carleton, Waltz, and Willow, the sand has, in places, been heaped up by the wind to heights of 620 to 625 feet above sea level.

Low ridges, with altitudes of 606 to 612 feet, extend from secs. 9 and 16 of Brownstown Township northward through Taylor into Dearborn, and are well defined near the village, where the profile of the electric railway shows a crest 600 feet broad and 617 feet above sea level, with a rather abrupt slope on the east. Farther north, behind the Detroit moraine, the shore line is not well marked, but around the southern margin of the moraine a nearly continuous ridge may be traced eastward across the southern tier of sections of Greenfield Township and across Springwells Township into Detroit. It crosses Warren Avenue as a low ridge but disappears between Buchanan and Poplar streets at about Seventeenth Street, although patches of sand show for a mile or more toward Grand Circus Park. Around the point of the Detroit moraine the wave or current action was too strong for the formation of a beach ridge, and a shelf was cut in the till slope at 605 to 615 feet above sea level. This is best displayed on Joseph Campau Avenue, between Campau Park and Monroe Street, but also on other neighboring streets running north from Monroe Street. Sand again appears on the east side of the moraine, north and east of Elmwood Cemetery. The beach may be traced northeastward across Gratiot Township, generally parallel to Gratiot Avenue but touching it in Erin Township.

Clay.—Local deposits of lacustrine clay occur in the vicinity of upper Detroit River, the largest lying just west of the Detroit moraine in Springwells Township, where the maximum thickness reported is 40 feet. The workable deposit covers nearly 5 square miles and has a surface altitude of 585 to 590 feet above sea level, the deposit thinning in all directions and merging into the glacial clay from which it was derived. In the deeper pits near the Pere Marquette Railroad three beds, quite distinct in color, texture, and composition, may be recognized. Beneath 6 to 12 inches of surface soil is a yellowish-brown layer of sandy clay, 2 to 4½ feet thick, under which is a 3-foot to 5-foot stratum stained red by the oxidation of the iron ingredients, and this in turn rests on a bluish bed, apparently the bottom of the deposit. The clay is finely laminated, some of the laminae being only 0.5 millimeter thick. It is practically free from bowlders and pebbles but contains small irregular concretions, known locally as "clay dogs."

Samples of the clay from the three beds have been analyzed by Elmer E. Ware, and the average of 15 analyses gives 62.01 per cent of silica, 12.6 per cent of alumina, and 4.35 per cent of ferric oxide. There is no marked difference between the three beds in the amount of iron oxide, but there is evidence of some leaching of calcium and magnesium compounds from the uppermost bed.

Other smaller deposits of similar lake clay lying east of the Detroit moraine are encountered in Grosse Pointe Township and in Detroit. In a tunnel beneath the river from the waterworks toward the head of Belle Isle a cat-tail bog, evidently of rather recent origin, was penetrated to a depth of 15 feet. Beneath it is a bed of brownish lake clay, containing shells and bowlders of crystalline rocks, some of which are glaciated. When visited by the author in March, 1902, this bed had been penetrated to a depth of 25 feet below the river level. Excavations in areas on the north show that the deposit is of small extent. The Ecorse salt shaft penetrated 4 feet of muck, 2 feet of mucky clay, and 4 feet of mottled brown, yellow, and blue clay containing shells, and the Woodmere salt shaft passed through blue glacial clay from the surface soil nearly to bedrock.

A shallow deposit of lake clay near Leesville, on Gratiot Avenue, was at one time extensively used in the manufacture of brick. The deposit averages only 3 to 4 feet in thickness, consists of blue and yellow clay free from stones, and extends for 2 miles along the avenue. The outline of the area is difficult to trace from its surface exposure, but it appears to be rather narrow and much smaller than the deposit in Springwells Township.

Deposits of Lakes St. Clair and Rouge.

The shore lines of Lakes St. Clair and Rouge are poorly developed and are represented only by weak sand or gravel ridges or by slight cuts in the gentle clay slope. The highest St. Clair beach is represented mainly by such a cut, 1 or 2 feet deep, in Erin and Gratiot townships, at an altitude of 590 feet above sea level or 14 feet above the present level of the lake. About the mouth of Conners Creek some sand ridges were developed, the material apparently having been contributed by the creek. Southwest of St. Clair Heights the beach disappears and is succeeded near the waterworks by a low bluff that extends across Jefferson Avenue and thence parallel to the avenue between it and the river.

The outlet of this lake past the Detroit moraine into Lake Rouge, though hardly more than a short strait, was in reality the beginning of Detroit River, and a low bluff was cut by the stream in the slopes on both sides. On the Michigan side the bluff crosses Jefferson Avenue near Wayne Street and extends westward, on the north side of Fort Street, to become the shore line of the first Lake Rouge.

The bed of Lake Rouge contains much sand, and consequently the surrounding beaches are better developed than those about the first Lake St. Clair. Between West Detroit and Fort Wayne, near the Boulevard, and extending west into Woodmere and Delray, are numerous well-defined sand ridges, with a general east-west trend. A prominent sand and gravel ridge, one-eighth to one-half of a mile wide and 16 feet above the river, furnished the site for the fort. On the south the sand gives out as the shore line curves through western Ecorse Township. The Grosse Isle moraine was encountered at Wyandotte Heights and the beach was deflected toward the river but was continued on both sides of the ridge at Trenton.

The water level of the western channel, leading into Lake Erie, may be traced as a sandy belt through secs. 11, 14, 23, 26, and 35, Monguagon Township. From Flat Rock to the mouth of Huron River strips of sand, apparently of delta origin, are scattered along the north side of the valley. Grosse Isle was already an island, although more completely submerged than now, and a low gravelly ridge was developed about its north end, where the wave action was most pronounced. South of Huron River no recognizable trace is left of the shore line of Lake Erie at that stage.

RECENT SERIES.

LACUSTRINE DEPOSITS.

Beaches and deltas.—The lower stages of lakes St. Clair and Rouge are marked by beach deposits and low bluffs so near the present level of Detroit River that they might easily be referred to a higher level of the present water bodies. They can not now be followed continuously, either because of their original weak development or because of their subsequent destruction. At Milk River Point the waves of the second Lake St. Clair cut into the Emmet moraine and formed a low bluff, which has been preserved by the concentration of bowlders from the moraine. Traces of similar cuts are found to the south in Grosse Pointe Township. South of Grosse Pointe Farms the beach leaves the lake and swings southwestward, as a sand ridge, through Cottage Grove and Fairview. At the time of Lake Algonquin the crest of the Emmet moraine in Grosse Pointe Township was an island in the first Lake St. Clair. At the second stage of the lake the island was nearly 5 miles long and half a mile wide, and deposits were made on all sides of it. West of this island ridge is a well-defined sand ridge, which is followed by Mack Avenue for more than 5 miles.

The lower Rouge beach is represented in the western part of Detroit by a low bluff in the grounds of Fort Wayne and by a ridge in Delray. Southward, across Ecorse Township, it is followed by the old highway, now on one side and again on the other, as a fairly well defined and continuous ridge. In Monguagon Township the beach lies close to the river, where it has been mostly destroyed. Traces of this stage of the river may be noted here on the islands and on the mainland, near the site of the Brownstown battle field, in the NW. ¼ sec. 1.

Small beaches are being formed here and there about the present lakes and along the banks of Detroit River, but they are too small to be shown on the map. Along much of the shore of Lake St. Clair and the banks of upper Detroit River and on a number of the islands in the river the banks are being cut back and a low bluff is being formed. As a result of this action a barrier of glacial bowlders from the Emmet moraine has been formed along the shore for 3 miles south from Milk River Point. Along lower Detroit River, north of the mouth of Huron River, and along the Lake Erie shore a low, narrow sand ridge separates the marsh from the open water and furnishes sites for cottages.

Delta deposits opposite the present mouths of the streams are also meager, especially compared to those deposited in some of the Pleistocene lakes. The accurate maps of the Coast and Geodetic Survey give little or no indication of such deposits, except about the mouths of Huron and Detroit rivers. The Huron has a recognizable delta, about 2 square miles in area, composed of sand and silt. About the west end of Lake Erie and extending up into the broad mouth of Detroit River a veneer of sand deep enough in places to be dredged for building material is spread over the glacial clay.

Dune sand.—Practically no formation of dunes is going on along the modern beaches in the district, but at numerous localities along the Wayne, Grassmere, and Elkton beaches dune deposits are being formed, especially in areas now under cultivation. The sand is rather fine-grained and free from pebbles and consists mainly of quartz with small amounts of the other common rock-forming minerals, mixed with some clay, which imparts to it a yellowish-brown color. Sections of such deposits show no stratification or only obscure traces of such structure. The sand was evidently derived originally from the till, being separated first by wave action, and there is no means of distinguishing the dunes of Recent age from those formed during the existence of the glacial lakes. Each group of dunes lies mainly west of the beach from which the material composing them was evidently derived. In addition to the well-defined dunes, sand of the same nature is being spread thinly over similar deposits of earlier age or upon the glacial and lacustrine clays.

ALLUVIUM.

Resting on the Pleistocene alluvial deposits and indistinguishable from them are thin deposits of sand and silt and some gravel, of Recent age. A relatively small amount of shifting material of this nature is found in the beds of the streams, but most of it mantles the Pleistocene flood plains and the marshes that border the mouths of the larger streams. The broadest areas of fluviatile deposits are along Huron and Rouge rivers and their tributaries, but narrow deposits extend up almost to the heads of even the smaller streams. Their combined areas would amount to at least 35 square miles. The gravel and sand are roughly stratified and the silt more regularly but less conspicuously so. In certain layers the silt grades into an alluvial clay, some of which has been used in making brick. No satisfactory data are available for determining the thickness of the combined Recent and Pleistocene flood-plain deposits, but it probably ranges from a fraction of an inch to 15 feet.

SWAMP DEPOSITS.

Muck and peat.—Beds of muck and peat have been and are still being formed in hollows in the flood plains, in the marshes about the mouths of the streams, and in other small areas in which the drainage is obstructed by deposits of sand or clay. So far as known they range in thickness from 1 to 8 feet, but they may be considerably thicker. Such deposits are numerous, but they are generally small, and only the larger ones have been mapped. The extensive swampy areas adjacent to Detroit River and Lake Erie are included with the alluvium in mapping. Other patches, having a total area of 3 or 4 square miles, are distributed throughout the district. One of the largest is in secs. 5, 8, and 9, Brownstown Township, and another extends from north to south across the southwest quarter of Royal Oak Township. A similar area, almost as large, lies in west-central Nankin Township, 2 miles northwest of Wayne. Remnants of a large swamp, known in early times as "Big Bear Swamp," are still found in secs. 5, 6, 7, and 8, Romulus Township.

Marl.—A thin layer of marl is generally found beneath the peat. It is fine, incoherent, and ashy white and contains shells and, in many places, remains of roots. The principal localities noted, but not shown on the map, are in secs. 5, 8, and 28, Brownstown Township and secs. 9. 10, 15, and 16, Sumpter Township.

Bog ore.—Local deposits of earthy iron ore and of red and yellow ocher have been formed here and there. Rather extensive deposits of such material occur west of Martinsville in secs. 9, 10, 15, and 16, Sumpter Township. They are reported to cover a square mile, to have an average thickness of 8 feet, and to rest on a bed of marl. Another small deposit is reported in sec. 22 of the same township. The extent and limits of the deposits are not known, and they are therefore not shown on the map. In the sites of former small ponds, now under cultivation, hard masses of yellow to brown spongy bog ore are brought to the surface by the plow.

STRUCTURE.

GENERAL FEATURES.

The structural features of the Detroit district are, in the main, simple, the successive strata overlying one another very regularly and in apparent conformity. The strata have been tilted to the northwest from their original nearly level position, but their dip is so slight that in small exposures the beds seem to be nearly level. Except for certain local irregularities the strata as a whole dip gently northwestward, toward the center of the Michigan basin. The tilting that produced the dip was accompanied by gentle warping or puckering of the strata, by jointing, and by slight faulting, but well records are neither sufficiently numerous nor so widely distributed as to permit the use of structure contours to delineate the structure of the district.

The average dip can be determined only from the records of deep wells, and most of those whose records are available are outside the district. The average slope of the top of the Monroe group from Detroit to Ann Arbor is 14.74 feet to the mile in a direction almost due west; measured on the Sylvania sandstone between the same points it is 15.7 feet to the mile. Along Detroit River the top of the Sylvania sandstone slopes northward at the rate of 27 to 32 feet to the mile, and from its outcrop in Monroe County to Ann Arbor it slopes northwestward at an average rate of 38.5 feet to the mile, practically in the direction of the dip. The available data show that the dip differs somewhat for the different strata and that it ranges between 25 and 40 feet to the mile.

In the lower Detroit River area local warping has increased the dip and somewhat changed the strike. In the Sibley quarry the dip ranges from 3.9 to 4.4 feet to the hundred and the strike from east of north to a few degrees west of north. When the Detroit River dolomite was exposed in the bed of the the river by the construction of the Livingstone Channel average dip of the strata was found to be S. 50° W. at the rate of 3.4 feet to the hundred. In the Anderdon quarry, in Ontario, the dip is S. 23° W. at the rate of 6 feet to the hundred.

LOCAL FEATURES.

Folds.—Folding has occurred in the district, both on a small scale, involving only a few strata, and on a larger scale, probably affecting several formations. The exposures of bedrock are so few, however, that the data regarding these flexures are far from complete. A broad, low anticlinal arch in the Detroit River dolomite crosses Detroit River at Stony Island from east to west, the strata along the axis attaining an altitude of 569 feet above sea level. To this fold is due the obstruction to navigation known as Limekiln Crossing, the so-called "sill" of the upper three Great Lakes. Its crest and southern flank were well shown in the wall of the Livingstone Channel, now submerged, in which 32 rock strata, having a total thickness of 102 feet, were exposed.

Grabau has found indications of an anticlinal fold, with two bordering synclines, in the pre-Dundee strata. The crest of the anticline trends about N. 60° E. and passes beneath Wyandotte. He determined the dip on the south limb of the anticline as 50 feet and that on the north limb as 60 feet to the mile. A broad, shallow trough involving the same strata is indicated by well records just outside the district at Milan, Ann Arbor, and Royal Oak. At Ann Arbor the top of the Monroe group is 50 feet below sea level, and it rises toward Royal Oak at the rate of 1.5 feet and toward Milan at the rate of 20.7 feet to the mile. A very broad arch is suggested by similar data regarding the top of the Traverse formation, which at Ann Arbor has an altitude of 200 feet above sea level. Toward the northeast, at least as far as Pontiac, about 34 miles, the slope averages 7 feet to the mile and in the opposite direction for the same distance, to Adrian, it amounts to 5¾ feet to the mile. Measured on the top of the Antrim shale the slope toward Pontiac is the same, but that toward Adrian is only 4 feet to the mile.

Domes.—At a few places in the lower Detroit River region the strata are warped into broad, flat domes instead of folds and at several such places the rocks either outcrop or lie near enough to the surface to be easily reached in quarrying. One of the best known domes is that of the Sibley quarry, just north of Trenton, where the Dundee strata, in an area of 1 or 2 square miles, have been warped 60 or 80 feet into a swell whose crest is about 595 feet above sea level. All sides of the dome are exposed except a part of the easterly slope, but a dip in that direction is inferred from the sharp drop in the bedrock surface, amounting to about 50 feet to the mile.

Joints and faults.—The deformation of the strata recorded in the folding and doming produced also innumerable vertical joints in all the strata that are exposed to observation and presumably in all the others to a considerable depth. Jointing is most noticeable in the brittle dolomites of the Monroe group and less so in the Dundee strata in the Sibley quarry. At the west side of this quarry two of the most prominent joints, involving all the strata exposed at the time of observation, trended N. 55° E. and N. 53° E. At the northwest corner of the quarry another such joint was observed, approximately perpendicular to the other two but curving to the east and showing a fault with a displacement of a foot. A close inspection of the joints in the artificial exposures in the district shows that a slight amount of faulting is common, but generally to the extent of only a fraction of an inch. No large faults have been observed in the district and none are to be inferred from the records of the deep wells.

Where the till deposits which mantle the bedrock of the district are well exposed they are permeated by an irregular system of joints of the same general nature as those described above but of course of much later date. Percolating water finds its way along the joints into the till and causes more or less discoloration of the clay.

At Rockwood and in the pits of the National Silica Co., just south of the Detroit district, the Sylvania sandstone is marked by inclined joints or partings, which are approximately parallel and dip 25° to 30°. They conform to neither the stratification nor the lamination of the sandstone but are nevertheless believed to be primary and to have been formed in some way during the period in which the sand was deposited instead of by later warping.

GEOLOGIC HISTORY.

PALEOZOIC ERA.

ORDOVICIAN PERIOD.

The earliest event recorded in the rocks known to underlie the district was the deposition of the calcareous sediment that now forms the Trenton limestone. This event was followed by the deposition of the clay that forms the Utica shale, and this in was turn followed, in later Ordovician time, by the alternate deposition of clay and calcareous mud, the entire series indicating shallowing of the Paleozoic sea in the region and increased erosion on the neighboring land. The nearest shore probably lay so far to the east that only the finer silt and clay reached the district during the Utica epoch. The prevailing red color of these deposits suggests that they were derived from a long-exposed and much weathered land surface. The later Ordovician sediments were deposited both offshore and in the open sea, the alternating conditions being caused by oscillations of the sea bottom and shifting of the strand or by varying rate of denudation of the adjacent land.

SILURIAN PERIOD.

PRE-SALINA TIME.

In the early part of the Silurian period the sea became shallower and activity of erosion on the adjacent land increased. Offshore and shore conditions alternated, favorable to the deposition of iron-stained clay, silt, and sand, and, so far as may be judged, generally unfavorable to organic life. Later, while the calcareous mud that now forms the Lockport dolomite was being deposited, the shore line was far enough removed and the general erosion of the adjacent land was so slight as to permit the accumulation of extensive beds of calcareous sediment unmixed with sand and clay. Lane suggests that this condition was the precursor of the arid conditions of Salina time. Probably the sediment was originally calcium carbonate and was converted into dolomite by the later addition of magnesium carbonate.

SALINA TIME.

Up to this time the marine conditions that were normal in early Paleozoic time probably prevailed throughout the region, and the interior sea was more or less directly connected with the great oceans. By the beginning of Salina time the land had emerged so far that a number of landlocked salt lakes, surrounded and separated by broad expanses of arid land, were formed in the region. The evaporation of water from these lakes exceeded the supply from the streams and caused concentration of minerals in the water, originally normally marine, which eventually led to the deposition of dolomite slime, calcium sulphate, and salt. The water was highly saline and contained few living organisms.

Several theories have been proposed to account for the extensive deposits of salt and the remarkable beds of anhydrite in parts of the Salina formation, which seem to indicate periodic or continuous influx of sea water and its concentration by evaporation. Grabau has pointed out that such influxes of normal sea water should have brought in swarms of marine animals, some of whose remains would have been buried in the deposits, and also that there are no normal marine strata which can be correlated with the Salina. He suggests what appears to the writer as the most plausible theory so far advanced, namely, that the sediments and concentrates which make up the Salina formation were deposited in lakes of the playa type surrounded by widespread desert land that was subjected to long-continued erosion and was drained by intermittent streams that flowed into the lakes. By such streams the salts in the pre-Salina marine sediments would have been dissolved, transported to the lakes, and there concentrated and deposited by evaporation, as they are deposited in similar basins to-day. It has been computed that the erosion of 400 feet of Lockport dolomite in the Great Lakes region would furnish the salt required for a bed covering 25 000 square miles to a depth of 100 feet, containing 500 cubic miles of salt. Furthermore, the erosion of such a mass of dolomite may have supplied the sediment from which the dolomite of the Salina formation was in large part derived. The remarkable fauna of eurypterids and ceratiocarids which are found elsewhere in some of the beds of the formation, and which are unlike any earlier fauna known, are believed by some to be fresh-water or brackish-water forms whose remains may have drifted into the denser lakes and there have been deposited.

BASS ISLANDS TIME.

The close of Salina time and the beginning of Monroe time were marked by no great change, either climatic or physiographic. An approach to more nearly normal marine conditions is suggested, but they were not yet attained. The sea again covered southern Michigan, and the character of the fossils shows that it transgressed westward across the district.

The climate became somewhat more moist until toward the close of Salina time, the change being accompanied by greater drainage and less evaporation. The conditions which in Salina time had led to the deposition of salt and gypsum were not again reached in southeastern Michigan, but dolomitic slime and clay mud, more or less intimately mixed, were washed into the basin.

The occurrence of beds of oolite 1 to 3 feet thick, containing granules like those found in Great Salt Lake, suggests the existence at that time of certain algae or bacteria, which now produce similar oolitic granules. Layers and films of carbonaceous matter interstratified with the dolomite also indicate the presence of some vegetation. Further evidence of the existence of shallow water and even of mud flats is furnished by ripple marks and sun cracks on the surface of some of the strata.

It has been supposed that the Salina formation originated from deposits of dolomitic slime derived by erosion from dolomite already in existence, but the fossil shells and oolitic grains were no doubt originally calcium carbonate and contained very little magnesium carbonate, indicating that some calcium carbonate had been altered to dolomite. The bed of very pure Anderdon limestone in the Detroit River dolomite shows, on the other hand, that no wholesale conversion of the strata has taken place, such as might have resulted from percolating magnesian waters. By whatever theory dolomitization elsewhere may best be explained, observations in the Detroit district indicate that it was here due to the alteration of calcium carbonate, an alteration which possibly was in some places completed by the action of imprisoned salts before the beds were hardened.

SYLVANIA TIME.

The shallow water of late Bass Islands time culminated in a second emergence of southern Michigan and the establishment of desert or semidesert conditions. One or two transgressions of the sea during the epoch seem to indicate that the shore line was not very distant and apparently lay south and west of the district. Wind and wave action on the west and northwest had resulted in the disintegration of previously formed beds of sandstone, such as the St. Peter and the Lake Superior, and the pure quartz particles were moved to southeastern Michigan and the adjacent territory. The sand grains were still further rounded and sorted and practically all the softer minerals were eliminated. In a rather large area the shifting sand was heaped into dunes, cross-bedded, and irregularly stratified. Local subsidence permitted an invasion of the sea and the formation of a bed of dolomitic mud, into which sand particles from the adjacent land were washed or blown. Emergence restored for a time the former conditions and permitted the further deposition of wind-blown sand directly upon the dolomite, where that existed and persisted, and in other places on the earlier deposits. When renewed submergence brought the epoch to a close the surface layers of sand were worked over by the waves, vegetation sprang up, and molluscan life was introduced. Later, percolating water introduced some insignificant amounts of silica along with calcium and magnesium carbonates and the sand particles were cemented into coherent sandstone. The addition of the silica led to the secondary enlargement of some of the granules, the added silica growing along the crystal axes of the original grains and becoming homogeneous with them.

DETROIT RIVER TIME.

Without any marked stratigraphic break the dolomitic beds of the Detroit River formation were laid down upon the Sylvania sandstone and conditions very similar to those of Bass Islands time were restored. The sea still persisted in the region of Lake Erie and in districts on the south. Under the conditions of Anderdon time corals and stromatoporoids flourished, and extensive reefs were built. Some oolite is embedded in the dolomites of the Detroit River formation but not so much as in the Bass Islands dolomite, which suggests that the water was ordinarily less concentrated. The invasion from the northwest of organisms later typical of the Devonian, culminating in Anderdon time, really began in Flat Rock time. Some of the more persistent species survived through the deposition of the Amherstburg into that of the Lucas, where they existed side by side with typical Silurian forms which had come in from the east and had become temporarily dominant.

The Anderdon limestone gives evidence of having originated in large part through the accumulation of calcareous animal remains, chiefly of corals, bryozoans, and stromatoporoids, in a shallow, open sea. Some of the beds, however, are so free from such fragments, so pure, compact, and delicately laminated, as to suggest that they may have been chemically precipitated.

DEVONIAN PERIOD.

DUNDEE TIME.

Silurian deposition in the Detroit district was brought to a close by emergence of the land. The disturbance responsible for this change caused also slight folding or wrinkling of the Silurian strata, but the irregularities so produced were largely obliterated by the erosion which took place during the deposition of the early Devonian beds on the east. Later the region was again covered by the sea and was inhabited by a fauna comprising forms which appear to have come in part from the Gulf of Mexico and in part from the Atlantic. A wonderful profusion of bryozoans, corals, crinoids, and mollusks lived in the clear, warm water, and their calcareous remains supplied the material for the limestone. The freedom from terrigenous sediment suggests an absence of extreme erosion on the neighboring land and probably a moderately dry climate. Fishes appeared for the first time in the region and were represented by strange forms of sharks, which contributed to the limestones some plates, spines, and teeth. From the soft parts of the organisms were derived small quantities of oil and asphaltum.

The sea of Dundee time also contained immense numbers of forms having siliceous skeletons, such as siliceous sponges, radiolarians, and diatoms. When conditions were especially favorable the deposition of their remains took place comparatively free from the calcium carbonate, and these thin strata of chert were laid down upon the ocean floor. There is evidence that solution and redeposition occurred, which gave rise to irregular nodules, thin seams and veins of chert, and the silicification of the calcareous fossils.

TRAVERSE TIME.

In Traverse time the climate evidently became moister and land erosion was increased. An uplift of land on the northeast, accompanied by some folding, quickened the rivers and led to the deposition of fine sediments in the Michigan region. The persistent bed of black shale first formed indicates that Traverse time was ushered in with offshore conditions which permitted the growth of much vegetation and the incorporation of carbonaceous matter into the sediments. Open-sea conditions similar to those of Dundee time subsequently prevailed especially toward the north, and were accompanied by oscillations of the sea bottom, which permitted the formation of alternate beds of calcareous and aluminous mud containing little if any carbon. The material consisted of levigated mud, which must have been gently drifted into the region from a distance and quietly deposited. Toward the close of the epoch elevation of the region on the south set in, accompanied by disturbances of the strata and weathering of the emerged surface. The elevation spread northward, bringing the Lower Peninsula of Michigan above the sea level while shales were being deposited on the east.

ANTRIM TIME.

Devonian deposition in southeastern Michigan closed with subsidence and partial reelevation. Offshore and estuarine conditions, with muddy seas and much floating vegetation, permitted the deposition of black mud and some sandy mud or sand. The vegetation is believed to have been somewhat similar to the floating fern of modern European rivers (*Salvinia natans*); the spore cases of both macrospores and microspores have been identified; and the Antrim sea is to be thought of as a great sargasso of such floating plants (*Protosalvinia*), which through the preserved spore cases supplied the high content of carbon that has given rise to the oil and gas so abundant in the formation. The fine sediments from the land were gently floated seaward and deposited very evenly over the sea floor. The concretions in the shales derived from these sediments are believed by Daly to have been formed in place while the deposits were being laid down. Aside from the fishes, animals found little to attract them to the region and there is a surprising scarcity of their fossil remains. The surrounding region seems to have had but slight relief and the climate was undoubtedly moist.

CARBONIFEROUS PERIOD.

MISSISSIPPIAN EPOCH.

BEREA AND COLDWATER TIME.

The Carboniferous period was ushered in with the establishment in this region of conditions favorable to the deposition of coarse sand. The stability that appears to have prevailed while the Antrim was laid down was interrupted by an elevation of the land, a consequent quickening of the rivers and increase of erosion, and an approach of the shore line from the east, probably accompanied by a moister climate. A slow subsidence permitted the formation of the Berea to a considerable thickness and established offshore conditions, temporarily like those of the Antrim. During this time the black shale stratum was formed. The bulk of the Coldwater formation, mainly light-colored shales accompanied by layers of limestone and sandstone, is the record of sedimentation under conditions shifting from those of the shore to those of open sea, and the epoch ended with a general shallowing. Vegetation seems not to have been very abundant except during what is regarded as probably the Sunbury part of the Coldwater epoch.

A commingling of faunas from several sources occurred during Coldwater time, which ended with a restoration of the littoral conditions under which the Mississippian epoch had begun. In southeastern Michigan the sandstone of the Coldwater appears to pass imperceptibly into the overlying Marshall.

This change in the character of the deposits presaged the emergence of the region, but the central part of the Lower Peninsula of Michigan was covered by a relatively small sea, in which were deposited strata of Pennsylvanian age. Later came final emergence from the sea and the close of Paleozoic deposition in the region.

POST-CARBONIFEROUS DEFORMATION.

Great orogenic disturbances which had been foreshadowed in the district by the oscillations during the Mississippian epoch culminated near the close of the Carboniferous period in a general elevation of eastern North America and terminated the Paleozoic deposition in the region. The attitude of the strata of the Lower Peninsula of Michigan, described in the Introduction to this folio, suggests that they had been considerably deformed before the final disturbance. This differential movement produced some of the main warping and puckering of the strata and probably most of the jointing and faulting. In Michigan, however, the disturbance was unaccompanied by marked crumpling or deformation of the strata and appears to have been almost wholly simple uplift.

MESOZOIC ERA.

Although somewhat elevated at the beginning of the Mesozoic era it is probable that the land surface was subdued in its general topographic features and that a long cycle of erosion or possibly a series of such cycles ensued. The region is not known to have been again submerged, but it is believed to have been affected by at least one considerable uplift, near the close of the era, after the upturned edges of the strata had been beveled and the general surface had been reduced to a peneplain.

The general direction of drainage in the district appears to have been easterly but data relative to the stream channels themselves are very meager. Broad, shallow troughs follow the northeast strike of the softer formations (Antrim, Traverse, and Sylvania) and possibly mark the positions of former valleys, but it is uncertain how much they are to be attributed to stream erosion in Cretaceous or Tertiary time and how much to erosion by the ice sheets in Pleistocene time.

CENOZOIC ERA.

TERTIARY PERIOD.

The Tertiary period appears to have been ushered in with an uplift of a few hundred feet, which gave new life to the streams and accelerated the general decay and erosion of the surface. The several strata of the district gave rise to a variety of residual soils—the sandstones passing into sand through the removal of the cementing material, the shale passing into heavy clay with little loss of bulk, and the limestone and dolomite being largely dissolved where they were exposed to percolating ground water. Part of the sand, iron, and clay impurities remained, forming a small amount of rusted and more or less sandy clay with a few nodules of chert. Beneath the mantle of soil and subsoil, where decay was less rapid, the rocks broke up into flakes and slabs and, deeper still, into large blocks. In this way loose material in large quantities was gotten ready for subsequent removal.

Toward the close of the Tertiary a second decided uplift of the region is believed to have taken place and the streams sank their beds still deeper into the rocks. The drainage of the district appears to have had a northeasterly course, probably following the same general direction as that of late Mesozoic time. It appears to have converged toward Detroit and there probably joined the main trunk stream, which, it is believed, flowed northward and thence perhaps southwestward to the Mississippi.

Water percolated into the beds of dolomite and limestone through the joints and fissures and, as a result of the increase in altitude, underground streams traversed the strata. Sink holes were formed at the surface and subterranean channels were developed beneath the district and still more so in that adjoining on the south. Such underground stream courses appear to have been tapped in the Law well at Dearborn, the Swan well on Grosse Isle, and the Oakwood salt shaft.

QUATERNARY PERIOD.

PLEISTOCENE EPOCH.

GENERAL EFFECTS.

The great ice sheets of Pleistocene time found upon their advent a featureless plain of bedrock mantled with a heavy burden of soil and loosened rock fragments. The relief of the rock surface was probably not more than 100 feet, the stream channels excepted, and that of the surface of the ground itself was probably somewhat less. The general effect of the glaciation of the region was to emphasize the relief of the rock surface by deepening the stream valleys, by producing here and there rock basins in the softer strata, and by the general differential erosion which left the ridges and knobs of harder strata projecting. Although the surficial deposits inherited from Tertiary time were swept away, the relief of the surface of the deposits which took their place was greater, as a result of the building up of the great terminal moraines.

The general slope of the land and the course of the streams, however, were not altered. The various residual, rusted, and leached Tertiary soils were replaced by a transported, more homogeneous, less weathered, and in every way fresher soil. Very marked changes in the flora and fauna occurred as a result of these changes in the soil and of the marked changes in climate brought about by the presence of the ice. From a region probably free from lakes of any size the Detroit district was eventually transformed almost wholly into a lake bottom, which has not yet completely emerged. The general effect of this lacustrine condition was to reduce the relief by cutting down the elevations and filling up the depressions, to diminish the general slope and somewhat modify it locally, to retard the drainage development over the area, and to produce great change and variety in the character of the soils.

EARLIER GLACIATION.

The presence in the drift of the district of copper and iron ores and sandstone brought from Lake Superior and the occurrence of striae of pre-Wisconsin age, having a southeasterly trend, make it appear probable that an ice sheet one or more times invaded southeastern Michigan from a center of accumulation west of Hudson Bay and known as the Keewatin center or from an area south of Hudson Bay which has been designated the Patrician center by J. B. Tyrrell. The general trend of the lake basins suggests that they may have suffered extensive erosion and been deepened and broadened in the general direction of the strike of the strata. That this ice movement fell short of the subsequent ones is shown by the fact that its till deposits were either destroyed or covered by younger sheets. In retreating the ice must have formed a system of morainic ridges and outwash features, but no traces of them have been clearly recognized in this region. Lakes also probably developed here and there along the ice margin.

ILLINOIAN GLACIATION.

The first great ice movement over the district of which we have direct evidence is probably that of the Illinoian from the Labrador center of dispersal. This plowed heavily and steadily across the rock surface in a direction S. 35°–45° W., and where the direction of the ice movement coincided approximately with the strike of the rock strata, as in southern Wayne and northern Monroe counties, broad, shallow troughs appear to have been excavated in the softer beds, separated by low, rounded divides of more resistant rock. These troughs in Monroe County are approximately parallel, ranging from S. 40° to 47° W. and averaging S. 43° W. As the strata in Wayne County curve to the east and broaden, these troughs lose in distinctness and only the Antrim trough is well defined, as previously described. The floor of this trough seems to be characterized by several rock basins, 40 to 80 feet deep, particularly in Van Buren, Dearborn, Royal Oak, Hamtramck, and Grosse Pointe townships, which give evidence of ice erosion.

At the Sibley quarry the boss of limestone served as a minor obstruction to the general ice advance but was readily overridden. As the ice mounted the northeastern slope it scoured heavily, and excavated a series of parallel grooves and basins, some 10 to 30 feet across and 2 to 10 feet deep so far as exposed. (See Pl. II.) The axes of these grooves and furrows have an average trend of S. 42° W., practically identical with that of the major troughs noted above. In a part of the bed of Detroit River laid bare in the excavation of the Livingstone channel the exposed surface of Detroit River dolomite was marked by a series of shallow, approximately parallel flutings, 2 to 4 inches across (see Pl. III), ranging in their bearings from S. 35° to 45° W. Associated with these features were patches of delicate striae averaging (35 observations) about S. 42° W. These flutings and striae were protected from subsequent ice and river erosion by a very compact till of probably Illinoian age.

In retreating to the northeast the Illinoian ice sheet probably left behind a full complement of moraines distributed about the main lobes, and these may have resulted in a series of glacial lakes essentially similar to those that marked the withdrawal of the Wisconsin ice. It is possible that some of the deposits of gravel and sand that underlie the Wisconsin till are lacustrine deposits of such a series of lakes, although they may have been deposited in the glacial lakes that formed in front of the advancing Wisconsin ice.

INTERGLACIAL TIME.

Between the disappearance of the Illinoian ice sheet and the incursion of the Wisconsin ice sheet there was a long period, which gave opportunity for pronounced weathering of the deposits and marked erosion by the streams. The till was rusted to a considerable depth, the calcium carbonate was leached out, and certain of the rock fragments became much decayed. The growth of vegetation over poorly drained areas gave rise to beds of humus and muck, which, where not destroyed by subsequent ice advances, form a distinct surface of division between the Illinoian and the Wisconsin tills. A study of the plant remains found in these deposits outside of the district indicates that the climate was somewhat milder than that of the present day and suggests that the Illinoian ice had been melted away for a considerable distance to the north or more probably had entirely disappeared.

Besides the weathering and leaching of the surface of the till it was subjected to continued stream erosion, and features were developed long since destroyed in the district. The disposition of the Illinoian moraines would control the drainage, and of these moraines we have but little trace. Leverett found reason for believing that the Fort Wayne moraine has a basement ridge of pre-Wisconsin age and that this ridge probably deflected the drainage on the eastern flank of the moraine to the southeast and south as it approached the next youngest moraine in the series. This would throw the drainage toward the Mississippi, although data are wanting in the district which might lead to the location of any of the stream courses themselves. Where the Illinoian till was not subsequently covered by later drift, the amount of stream erosion, as Leverett has estimated, is five times greater than that shown upon the surface of the late Wisconsin till.

WISCONSIN GLACIATION.

Multiple character of the Wisconsin stage.

Studies of the relations of certain moraines, till sheets, and glacio-lacustrine deposits outside of this district, as well as of the directions of glacial striae, lead to the belief that there were at least three distinct advances of the ice during the Wisconsin stage of glaciation. Although the deposits in the district give no evidence of such fact, there are striae in Wayne and Monroe counties which appear to mark two such movements. The earlier of the two, at the Sibley quarry, south of Wyandotte, averaged about S. 31° W., with a range of 20°, and the later ran N. 29° W., with a range of 43°, making an angle of approximately 120° with the first. Outside the district, in Monroe County, this later striation swings to the west and, as the Ohio line is reached, to the southwest. A still earlier direction of movement has also been made out at the same locality from striae bearing S. 65°–78° W., or approximately west-southwest. These are regarded as marking one of the directions of earlier Wisconsin movement. The preservation of the grooves and striae produced by the Illinoian ice indicates that the destructive work of the Wisconsin ice was not excessive in the district at any stage. Except where protected by the Illinoian (?) till, the surface of the limestone and dolomite exposed in the lower Detroit River region reveals, often perfectly, the glaciation resulting from the Wisconsin ice. This is still well shown at the Sibley quarry. (See Pl. II.) Here may be seen all the criteria for determining the direction of ice movement—knobs and trails, lee and stoss phenomena, broadening gouges, chatter marks, and plucking.

Lobation of the Ice.

During the recessional stages and doubtless also during the maximum advance across Michigan the Wisconsin ice sheet moved forward in a number of lobes, as shown in figure 8, the movement being adjusted to the large topographic features of the region. The large valleys and basins which it encountered permitted easy flow and were occupied by the lobes. Parts of two lobes completely covered this Detroit district as a result of the converging movement of ice from the Huron and the Erie basins. This combined Huron-Erie lobe, pursuing a southwesterly course, extended not only across southeastern Michigan but across adjacent portions of Ontario, Ohio, and Indiana, apparently a repetition of what took place in Illinoian time. The Huron lobe brought material from the north and east and the Erie lobe, during the waning stages, actually moved rock débris northwestward across the area, as first recognized by Winchell. This anomalous direction of

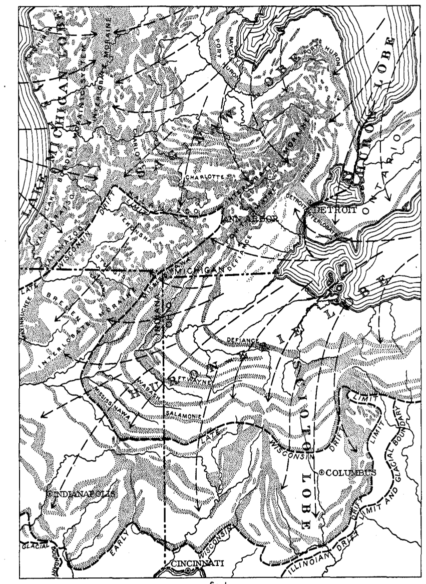


FIGURE 8.—Map of the glacial moraines in southern Michigan and portions of adjacent States, showing also the lobation of the ice sheet. The direction of ice movement of the different lobes is indicated by arrows and the limits of the ice at different stages by heavy dashed lines. (After Frank Leverett.)

movement, verified by the striae mentioned above, is explained by the fact that most of the district at that stage of glaciation lay northwest of the Erie lobe and that the direction of movement of the ice is approximately at right angles to the margin. In harmony with this view it is to be noted that the general course of the frontal moraines and bowlder belts that mark successive stages of the waning Erie lobe is from northeast to southwest.

Along the line of junction of the two lobes, extending from Birmingham, just north of the district, southeast to and beyond Detroit, there was formed the subglacial moraine, a type exceptional in this region. This has been described under "Stratigraphy" as the Detroit interlobate moraine and is believed to have originated subglacially as the joint work of the two lobes, the Huron component forcing the ground morainic material to the southwest and the Erie component squeezing it to the northeast. This theory of formation explains satisfactorily the very subdued character of the moraine, its freedom from surface bowlders, and the fact that its trend is approximately at right angles to the recognized frontal moraines.

Recessional stages.

The general direction of retreat of the ice front from this area was from northwest to southeast, and although it was probably slow it was not continuous. There were periods of prolonged halt of the ice margin, during which the frontal moraines and bowlder belts were formed, and at least three pronounced stages of readvance were recorded in the lacustrine deposits. The first main halt was of an oscillatory nature and formed the outer and inner ridges of the Defiance moraine. The drainage from the ice was concentrated about the village of Northville during the formation of the inner ridge, and glacial streams, discharging at the ice front, deposited great quantities of gravel and sand, which gave rise to the numerous kames in that vicinity. This drainage was collected into a main stream during the formation of the inner ridge, and this stream followed the glacial margin to the southwest, across Washtenaw County, eventually reaching glacial Lake Maumee, which had already come into existence on the south. It seems probable that a narrow marginal lakelet lay in this channel for a time and extended across Northville and Novi townships.

The two ridges of the Defiance moraine were the only morainal ridges deposited on land within this area. The other moraines, produced respectively by the Huron and the Erie components of the glacier, were deposited in the waters of glacial Lake Maumee. The Scofield bowlder belt was apparently formed by the Erie lobe simultaneously with the Birmingham moraine deposited by the Huron lobe. The Mount Clemens moraine resulted from the Huron lobe, but its correlative has not been identified in the Erie basin, either because of its original weak development or of its destruction by later ice advance. The Emmet moraine north of Detroit and the

Grosse Isle moraine on the south apparently mark a readvance and the last halt of the ice front within this area. The two lobes were at that time still united but were separated in Ontario at a considerably later stage. With the glacial drainage directly into the lakes along the ice front there was no opportunity for the production of kames, outwash gravel deposits, or valley trains in channels.

Formation of glacial lakes.

General conditions.—So long as the ice front lay south of the low divide that separates the Erie basin from that of the Ohio, the water escaped freely southward from the ice and no marginal glacial lakes were formed, but as soon as the melting of the ice moved the glacial margin northward across this divide, the water began to be ponded in front of the ice and a series of small isolated pools came into existence, which had independent outlets and were at different levels. As the ice front continued its retreat these small glacially dammed lakelets increased and joined and found an outlet at the lowest available place on the divide between the Erie and Ohio

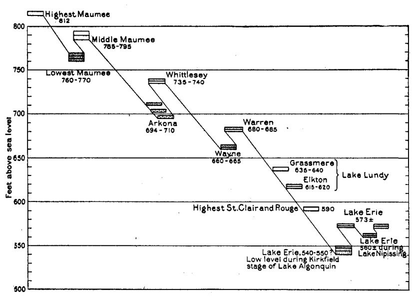


FIGURE 9.—Diagram showing altitude and time relations of the shore lines of the glacial lakes of the Detroit region, oldest at the left. Beaches submerged by later expansion of the ponded waters indicated by dotted pattern. The lower St. Clair and Rouge beaches, 580 feet elevation, correspond to the later stage of Lake Nipissing.

basins. As the other lobes of ice shrank within their respective basins, gradually expanding glacial lakes, similar to those of the Huron-Erie basin, came into existence. In time these became confluent, the melting ice uncovering successively lower outlets. There thus resulted a complicated series of lakes in the Great Lakes region, which were intimately associated with and the correlatives of the Wisconsin stage of glaciation. This complication arose from the relations of the general topographic features of the region, the deepening of outlets, the differential uplift of the land, and the shifting of the ice fronts back and forth. The unraveling of the complicated history of these glacial lakes, whose relative order and elevation are shown in figure 9, is the result of the studies of several geologists,

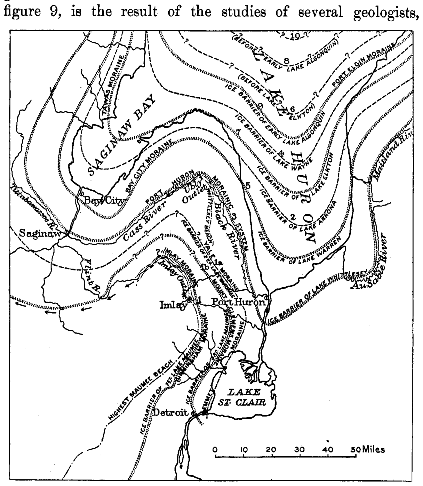


FIGURE 10.—Sketch map showing the position of the ice front when it formed the barrier or dam of successive stages of the glacial lakes.

Dotted lines represent advanced positions of the ice whose moraines were not later overridden by the glacier; the moraine names are placed where existing moraines are well developed. Dashed lines represent retreatal positions of the ice whose moraines were later overridden by the glacier and largely destroyed. The numbers (1 to 10) show the order in which the ice barriers occurred, the first being divided into three minor stages, indicated respectively by 1, 1a, 1b.

notably those of F. B. Taylor and Frank Leverett. The illustrations that form figures 9 to 17 of this folio are in large part copied from their report on the history of the Great Lakes.[1] The positions of the ice barriers of the various lake stages are shown in figure 10. The advent of the ice in the region must also have been accompanied by somewhat similar lakes, but they were formed in reverse order and probably were less complicated.

[1] U. S. Geol. Survey Mon. 53, 1915.

Lake Maumee.—In the Maumee Valley, when the ice front began to withdraw from the Fort Wayne moraine, the first and highest stage of Lake Maumee came into existence, the drainage being across the Fort Wayne moraine into the Wabash and thence to the Ohio. The lake assumed the shape of an arrowhead, the point at the site of the present city of

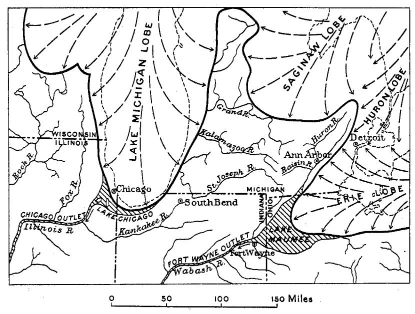


FIGURE 11.—Map showing the first (highest) stage of glacial Lake Maumee, which was dammed by the front of the ice sheet when it occupied the position of the Defiance moraine and the lake outlet was at Fort Wayne.

Its waters followed the course of Wabash River to the Mississippi. This lake did not at first extend into the Detroit district, but as the ice front receded from the Defiance moraine the lake waters spread into the Detroit district and formed a beach on the east side of the moraine at approximately the same level.

Fort Wayne, one barb extending east across northwestern Ohio, the other north along the ice margin into Michigan, as shown in figure 11. While the ice was halting at the Defiance moraine it formed a dam about 100 miles in length from Findlay, Ohio, around by Defiance, to Adrian, Mich. At this stage the lake was 40 miles wide from east to west, 75 miles long from Fort Wayne to either Adrian or Findlay, and about 60 feet deep at Defiance. The present altitude of the shore line at the outlet is 785 to 790 feet above sea level, and a beach 5 to 7 feet high was thrown up by the waves. The old outlet, which may still be traced from Fort Wayne for 25 miles to the Wabash at Huntington, is about a mile wide and is strewn with bowlders and cobbles from the 20 to 80 feet of drift that has cut been away.

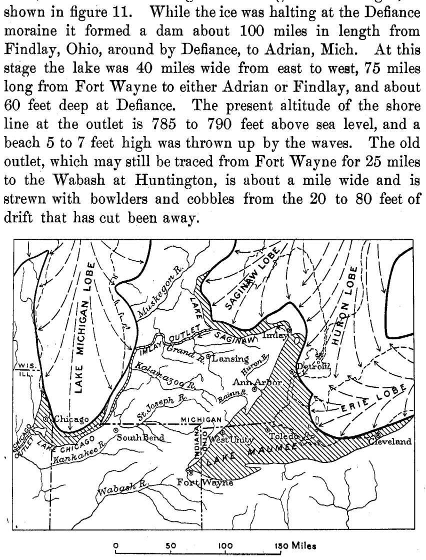


FIGURE 12.—Map showing the third stage (medial elevation) of glacial Lake Maumee, which was dammed by the front of the ice sheet when it occupied the position of the Mount Clemens moraine and the lake outlet was past Imlay, Mich., westward through Grand River to glacial Lake Chicago.

The second (lowest) stage had practically the same outlet but at a somewhat lower level.

At first the lake waters did not reach the Detroit area, but as the glacial front withdrew from the Defiance moraine the water moved in between the ice and the moraine. Thus sheltered the lake developed a poorly defined beach at the same general level along the eastern flank of the moraine, as shown on the Wayne geologic map.

As the ice melted back, a lower outlet than that at Fort Wayne was opened past the present site of Imlay City, Lapeer County, Mich., and the water of the lake fell 20 to 25 feet. This new outlet, called the Imlay channel, led by Flint and Durand, Mich., to Grand River, which then discharged into glacial Lake Chicago, formed at the head of the Lake Michigan ice lobe. This latter lake in turn drained southwest into Illinois River and thence to the Mississippi. The Imlay channel seems at that time to have been neither low enough nor wide enough to draw the full discharge of the expanded lake, and the Fort Wayne outlet for a time continued also in commission. This phase of the lake had but a short existence, lasting only while the ice front retreated to a point a short distance northeast of Imlay City, where an outlet 15 feet lower was opened, and the water was drawn down to that level. While this outlet remained in commission the second or lowest Maumee beach was formed. The present level of this beach is 755 to 765 feet.

A later readvance of the ice front closed this lower outlet and raised the level of the lake until it again discharged through the Imlay outlet. This it enlarged to a valley about half a mile wide, floored with sand and gravel. As the lake rose to this level and the water gradually encroached upon the former lake bottom, pebbles from the till were worked up the slope by the waves and there was formed a better defined and more gravelly beach ridge than that formed as the water was receding. The submergence of the lowest Maumee beach led to its partial destruction in places and to its partial concealment through the deposition of lake sediments. The outline of this latest stage of Lake Maumee is shown in figure 12 which was determined by mapping its beach and locating the Mount Clemens moraine, which formed the ice dam. The present level of the lake beach at this stage may be given as 775 to 780 feet above sea level, though the crest of the beach runs a few feet higher, 785 to 795 feet.

Lake Arkona.—Renewed melting and recession of the ice front to the northeast from the position of halt near Imlay City developed an expanse of water larger than any of the preceding lakes but at a lower level. When the ice uncovered the "thumb," or Saginaw Peninsula, a channel several miles in width was opened between the land and the ice front in Huron County and the glacial waters in the Erie basin were lowered and became confluent with those of glacial Lake Saginaw, giving rise to glacial Lake Arkona. The outlet thence was to Grand River and Lake Chicago.

In dropping to this level, the waters must have temporarily passed through the Ubly outlet and Lake Whittlesey must have had a preliminary existence. The ice advance terminated the life of Lake Arkona and destroyed the moraine that must have been formed during its existence, so that the mapping of its iceward limits is impossible. Lake Arkona is thought to have occupied much of the Saginaw basin and to have extended east beyond Buffalo about 40 to 50 miles into New York. The ice margin is believed to have rested about 25 miles northeast of Bad Axe, Mich., and to have looped across the bed of Lake Huron to the north of Port Huron. The lake stood successively at four different levels, which are now between 710 and 690 feet above sea level, and judged by the size of the deltas formed about its margin was of long duration. The washed-out character of the beach, as seen in the Detroit area and elsewhere, is apparently due to its later submergence of 25 to 30 feet during the main stage of Lake Whittlesey. In places within this area lake sediments have obscured the small amount of beach deposit remaining and rendered the tracing of the beaches all the more difficult.

Lake Whittlesey.—A readvance of the glacier on the end of the "thumb" in Michigan raised the water in the Erie basin above the Arkona level and initiated Lake Whittlesey. The drainage channel which afforded an outlet and determined the level of the lake, crosses the crest of the "thumb" at the village of Ubly, Huron County, Mich., and leads thence southwest to Cass City. This channel is from half a mile to a mile in width, is floored with gravel and bowlders, and in a distance of 22 miles descends about 70 feet. Two smaller channels enter the main one from the village of Tyre, 4 miles southeast of Ubly. These channels carried the waters of Lake Whittlesey into Lake Saginaw, which in turn discharged into Grand River and Lake Chicago. The present level of the beach of this lake is 735 to 740 feet. The general form and size of this lake is shown in figure 13, along with the contemporary lakes Saginaw and Chicago and their drainage channels.

The Huron and Erie ice lobes were separated from each other for a distance of 50 miles. The Huron lobe stood at the main moraine of the Port Huron morainic system in about 150 feet of water and had a frontage of 200 miles. The Erie (or Ontario) lobe probably had its apex in Ontario on a line between Port Huron and Buffalo. The water thus

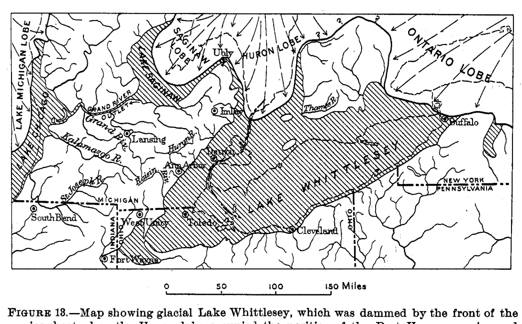


FIGURE 13.—Map showing glacial Lake Whittlesey, which was dammed by the front of the ice sheet when the Huron lobe occupied the position of the Port Huron moraine and the lake outlet was westward past Ubly, Mich., into glacial Lake Saginaw and thence through Grand River to glacial Lake Chicago.

Glacial Lake Arkona, which preceded Whittlesey, had a somewhat similar outline, though at a lower level, and was confluent with glacial Lake Saginaw.

impounded formed a lake twice as large as the present Lake Erie. The southern margin of the lake followed closely the present southern shore of Lake Erie from Buffalo to Sandusky, thence extended up the Maumee Valley nearly to the Indiana line, turning abruptly to the northeast. The old shore line may be traced across the northwestern part of the Wayne quadrangle and thence to the outlet at Ubly. The lake built up a strong beach ridge of sand and gravel, which would seem to indicate considerable age. This, however, does not correspond to the relatively weak development of deltas formed during the stage. The strength and gravelly character of the beach are probably rather due to the same conditions that accentuated the middle Maumee beach, the rising water accumulating the pebbles and gradually working them up the slope until the beach in places acquired the appearance of a railroad embankment.

Lake Wayne.—Withdrawal of the ice entirely from the "thumb" of the Lower Peninsula of Michigan allowed the waters of the Erie-St. Clair basin to become confluent again with those of Lake Saginaw, and the combined bodies of water constituted Lake Wayne. The lake level, however, was 80 to 85 feet lower than that of Lake Whittlesey. This lowering of the level of the water is believed to have been due to the temporary opening of an outlet located just south of Syracuse, N. Y., which allowed drainage into the Mohawk and thence into the Hudson. The area submerged was somewhat contracted in Ontario, Ohio, and Michigan, but this loss was more than compensated by confluence with the water in the Saginaw basin and by the extension of the lake waters in New York so as to include the Finger Lake region. The present site of Niagara Falls was submerged in 200 feet of water, drainage down the St. Lawrence being still prevented by the presence of the great ice sheet. The outline of the lake at this stage has not been completely determined, but its outlet was the same as that of the later Lake Lundy shown in figure 15. In Michigan the ice border is believed by Taylor to have been located 25 to 30 miles northeast of Bad Axe. The waves extracted sand mainly from the till at this stage, and the water line is much obscured by wind action, the general altitude at present ranging from 660 to 665 feet. Bars were formed in the shallow waters in front of the beach at somewhat lower levels. The prevailing winds were apparently easterly at this stage, and they heaped up dunes to the west and distributed the sand over a broad belt. Within the Detroit area there is but slight evidence of later submergence of the beach similar to that to which the lowest Maumee beach and the Arkona beach were subjected, but from evidence farther north Taylor concludes that they had similar histories. Readvance of the ice closed the Syracuse outlet and raised the level of the water about 30 feet, so that discharge to the west was resumed.

Lake Warren.—As in the case of the middle stage of Lake Maumee and Lake Whittlesey, Lake Warren theoretically must have made its first appearance when the waters of the latter in dropping to Lake Wayne stage reached the level that is now 675 to 680 feet above sea level. At this level a channel three-quarters of a mile to a mile wide and about 50 miles long, leading from the Saginaw basin by way of the Grand River valley to Lake Chicago, was opened. This first stage lasted only while the ice front in New York was retreating as far as was necessary to allow discharge through the Syracuse outlet. The readvance of the ice that terminated Lake Wayne restored the level of the water, and Lake Warren entered upon its main stage.

The position of the ice dam as determined by Taylor was a little south and west of Alpena, Mich., and just south of Rochester, N. Y. The Erie glacial lobe had disappeared, the ice front had retreated far to the north in Ontario, and had left

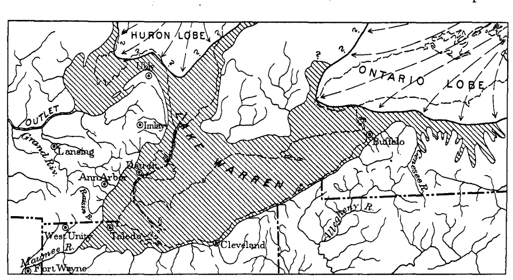


FIGURE 14.—Map showing glacial Lake Warren, which was dammed by the front of the ice sheet when it had retreated to the vicinity of Rochester in New York and Alpena in Michigan and the lake outlet was from the Saginaw basin through Grand River valley to glacial Lake Chicago.

a broad reentrant between the Huron and the Ontario lobes. The general form of the lake and its relation to these lobes is shown in figure 14.

Lake Lundy.—Further withdrawal of the ice front in the vicinity of Syracuse, N. Y., reopened the outlet to the Mohawk and the Hudson and allowed the level of Lake Warren to fall about 40 feet. A lake at the level of Lake Wayne probably came into existence again for a brief time when the level of its outlet was reached, but the water soon dropped to a lower level. The lake resulting is now known as Lake Lundy. (See fig. 15.) It was characterized by two quite distinct phases, during both of which the outlet is believed to have been in the vicinity of Syracuse, N. Y. The earlier phase is represented by the Grassmere beach; the later phase, known also as Lake Dana and Lake Elkton, by the Elkton beach. So far as may be inferred from the data in the Detroit area the Grassmere beach stood about 25 feet higher than the Elkton beach. In the "thumb" or Saginaw Peninsula, however, the vertical interval between the beach crests is 70 to 75 feet and in western New York from 80 to 90 feet. This discrepancy was caused by unequal uplift of the land, as explained under the heading "Tilting of land surface." In the entire series of glacial lakes so far outlined each retreat of the ice front was followed by an advance, which gave a double phase to each of the lakes, with the exception of the first or highest Lake Maumee. Similarly during the life of Lake Lundy an advance is indicated following the retreat in western New York, but the oscillation was not sufficiently pronounced to affect the outlet materially or to submerge the Elkton beach.

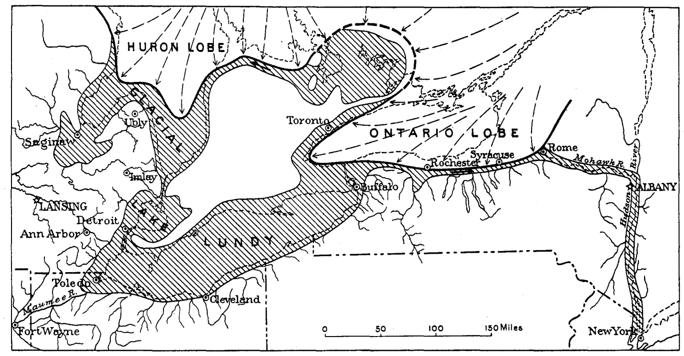


FIGURE 15.—Map showing glacial Lake Lundy, which occupied all of the basins of Lakes Erie and St. Clair and part of Lake Huron and whose discharge was past Syracuse, N. Y., down Mohawk River into the Hudson.

Glacial Lake Wayne, which preceded Lakes Lundy and Warren, had a similar outlet to Lake Lundy but stood somewhat higher.

In the Detroit area the waves of this wide lake gathered mainly sand from the till, which they constructed into a broad, low beach ridge, the wind building this into dunes on the landward side and the surf heaping it into bars on the lakeward side. The streams contributed sand and fine pebbles, from which poorly outlined deltas of relatively small size were constructed during each of the stages. This stream sediment, along with that obtained directly from the lake floor, was drifted alongshore by local currents and built into hooks and spits where conditions were favorable. The finest of this sediment remained in suspension for a longer time and after heavy on-shore winds or violent freshets reached the open water, there to be deposited in the regular layers of lacustrine clay.

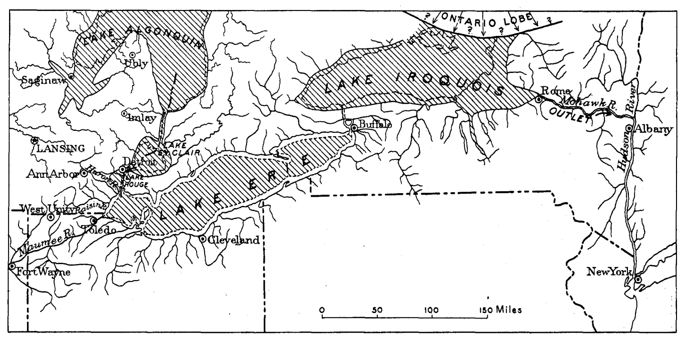


FIGURE 16.—Map showing the lower part of glacial Lake Algonquin and Lakes St. Clair, Rouge, Erie, and Iroquois, the drainage from which entered the Mohawk Valley at Rome, N. Y., and passed into the Hudson.

The front of the ice sheet dammed the St. Lawrence outlet and held back the waters of glacial Lake Iroquois. Lake Erie was smaller than it is at present, as shown by the shaded area inside the present lake outline.

The work of the waves, as they swept around the nose of the Detroit interlobate moraine, was largely of a constructive nature during the Grassmere stage, giving rise to the sand ridges of the village of Highland Park. During the Elkton stage, however, the waves cut a shelf and low bluff in rounding this exposed till ridge, the "Grosse Pointe" of Lake Lundy time. This feature is best shown in the city of Detroit between Monroe and Macomb streets, in the vicinity of Joseph Campau Avenue, but it continues both east and west for many blocks.

Eventually the melting back of the ice opened a new and lower outlet from Lake Lundy at Rome, N. Y., which lowered the water so that the lake was separated into a chain of several lakes at different levels. Niagara Falls began when the water level had fallen so low that glacial Lake Iroquois, the successor of Lake Lundy that occupied the basin of Lake Ontario, was separated from Lake Erie, the next higher lake of the chain.

Lake Algonquin and associated lakes.—The successor of Lake Lundy in the Lake Huron basin is called Lake Algonquin. This lake had a complicated history, the details of which have been worked out by Taylor and an outline of which is necessary in order to understand what happened in the Detroit district. At its first stage, when the ice front lay near Alpena, Mich., and Port Elgin, Ontario, it covered the southern half of Lake Huron and discharged southward through the Port Huron outlet. As the ice melted away northeastward this lake enlarged and united with lakes that were formed in the Michigan and Superior basins to make the single vast sheet of water also called Lake Algonquin, the largest of the glacial lakes in the St. Lawrence basin. Soon the further melting of the ice opened an outlet at Kirkfield, Ontario, through Trent River into glacial Lake Iroquois, and for a time the water was diverted from the Port Huron outlet. Eventually, however, the continued differential uplift of the land to the northeast closed the Kirkfield outlet and raised the water level so that the lake again began discharging through the Port Huron outlet. Goldthwait has shown that the highest Algonquin beach in the Lake Michigan basin skirts the head of that lake as the "Toleston" beach. At this stage, therefore, Lake Algonquin probably discharged also through the old outlet of glacial Lake Chicago to Illinois and Mississippi rivers. The use of these three outlets—Port Huron, Kirkfield, and Chicago—perhaps part of the time simultaneously, so complicated the history of Lake Algonquin that its successive stages may eventually need to be distinguished by separate names.

In none of its stages did Lake Algonquin reach as far south as the Detroit district, but beaches of correlative age are found in the district, encircling the margin of Lake St. Clair and that of the extinct Lake Rouge. These lakes were the successors of Lake Lundy in the basin of Lake St. Clair and in the shallow basin about the mouth of River Rouge. While the Port Huron outlet of Lake Algonquin was in use the discharge from that lake passed through them to Lake Erie, as shown in figure 16, and they were of fair size and built small beaches in places about their margins. These benches now stand about 590 feet above sea level, a few feet lower than Lake Algonquin and about 15 feet higher than the present level of Lake St. Clair. When the discharge of Lake Algonquin was diverted to the Kirkfield outlet these smaller lakes must have shrunk to insignificance, as they then received only the drainage from local streams, but with the resumption of the discharge through the Port Huron outlet they returned nearly or quite to their former size.

The lake that was left in the Erie basin after the fall of Lake Lundy represented the first stage of the present Lake Erie, as, not being held in by an ice dam, it was no longer a "glacial" lake. Lake Erie was thus the first of the present Great Lakes to come into existence. At this first stage it received the full discharge of Lake Algonquin and was nearly as large as the present lake. (See fig. 16.) Its outlet was at Buffalo but was relatively lower than now, and the lake level was somewhat lower than that of the present lake. No record of its existence at this stage is preserved in the Detroit area. When the flow through the Port Huron outlet was interrupted Lake Erie received only local drainage and was much smaller and lower than at present. The beaches formed then are now submerged, and the size and depth of the lake at this low stage can not be closely determined. A record of its existence is preserved in the Detroit district, however, for the streams tributary to the lake cut down their channels in adjustment to the low base-level and the present drowned condition of these streams near their mouths is largely due to this downcutting. When the discharge of Lake Algonquin through the Port Huron outlet was resumed Lake Erie regained approximately its first size and level.

The melting back of the ice front eventually left only a narrow lobe of ice in the east-west trough that leads across the uplands of Ontario from North Bay, on the present Lake Nipissing, to the valley of Ottawa River. This lobe for a time held back the water of Lake Algonquin, which had enlarged to cover the Georgian Bay region, but at length it melted away and allowed the lake to discharge through Ottawa River to an arm of the sea which then occupied the St. Lawrence Valley and is known as the Champlain Sea. For a time both the North Bay and Port Huron outlets were in use, but as the North Bay outlet was cut down the lake level was lowered and the Port Huron outlet was again temporarily abandoned.

Inasmuch as the opening of the North Bay outlet marks the final disappearance of the direct influence of the ice sheets on the basins of the Great Lakes and the St. Lawrence, it is regarded as marking also the transition from the Pleistocene to the Recent epoch in this region.

RECENT EPOCH.

NIPISSING GREAT LAKES AND ASSOCIATED LAKES.

Lake Algonquin was the last of the "glacial" Great Lakes. It was succeeded, when the North Bay outlet was clear of ice, by the Nipissing Great Lakes, which occupied the basins of the present upper three lakes but were somewhat deeper and extended slightly beyond the present shores, so that the lakes in the Superior, Michigan, and Huron basins were confluent. (See fig. 17.) They discharged at first through the North Bay outlet, but renewed uplift of the land on the northeast at length turned part and finally all of the outflow back to the Port Huron outlet, the Chicago outlet having been abandoned when Lake Algonquin came to an end. Since the closing of the North Bay outlet the upper three lakes have discharged entirely through the Port Huron outlet until within the last few years, when a small part of the discharge has been again diverted to the Mississippi by the reopening of the Chicago outlet in the construction of the Chicago Drainage Canal.

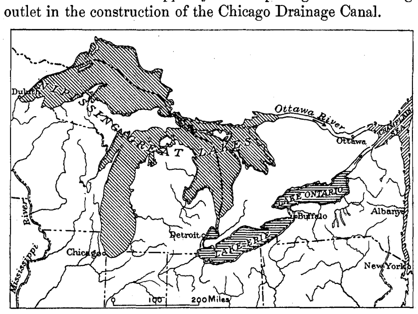


FIGURE 17.—Map showing the Nipissing Great Lakes during their closing stage of two outlets, one through Ottawa River and the other through Detroit River into Lakes St. Clair, Erie, and Ontario. The water flowed eventually into the Champlain Sea, which occupied the St. Lawrence Valley and the basin of Lake Champlain.

Like Lake Algonquin, the Nipissing Great Lakes failed to reach the Detroit district, but beaches are found which were formed at that time about Lake St. Clair and Rouge and which stand 5 to 7 feet above the present level of Lake St. Clair. Lake Rouge was soon drained by the deepening of the channel of Detroit River when flow was resumed through the Port Huron outlet, and only its bed and shores remain as testimony to its former existence.

When the water was dropping from the first St. Clair stage, during the life of early Lake Algonquin, the Detroit moraine is conceived to have served as a temporary dam, across which the water cut its way at several points simultaneously, digging channels and depositing the sand and gravel in Lake Rouge. Taylor recognizes two such channels in Detroit, and others were probably formed and destroyed in the present bed of the river, for the permanent flow would probably be in the course of the largest stream. Congress Street, east of Woodward Street, and Baker and Labrosse streets, west of Grand Circus Park, lie in the axis of one of these channels. The great quantity of sand and gravel which lies between West Detroit and Fort Wayne and between the Boulevard and River Rouge at an altitude of 585 to 595 feet, is believed to have been deposited chiefly through these channels and only a minor portion of it by the present Rouge. Near Trenton, Grosse Isle, and Amherstburg a much more complicated system of such distributaries has been mapped by Taylor (see fig. 18), one of which, the Thorofare, is shown in Plate XI. Their course in this region seems to the writer to have been determined very largely by the morainic ridges of the Grosse Isle moraine, hence there was comparatively little erosive work and little or no deposition about their mouths. The water found and occupied the depressions between these morainic

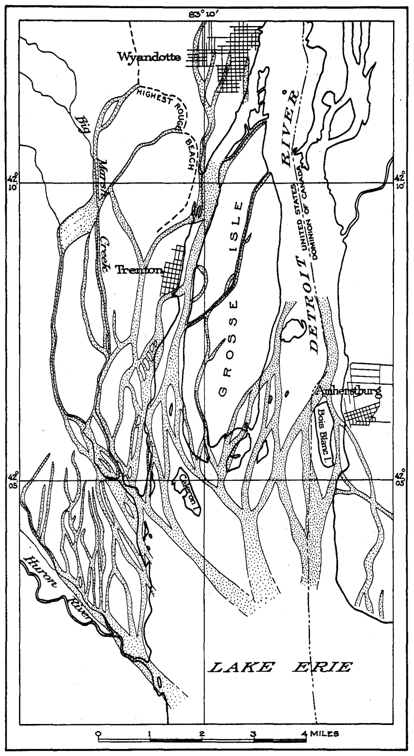


FIGURE 18.—Map of the distributaries of the lower part of Detroit River during the stages represented by Lake Algonquin and the Nipissing Great Lakes.

By Frank B. Taylor. Distributaries are stippled with dots.

ridges in the lower Detroit River region instead of carving them entirely from the till plain as believed by some.

TILTING OF LAND SURFACE.

The Nipissing Great Lakes at length gave place to Lakes Superior, Michigan, and Huron. This resulted from the differential uplift of the land, to which reference has been made (p. 16), a movement which set in soon after the ice front began its retreat from the region, continued throughout the lacustrine history, and is apparently still in progress. When the bed of the North Bay outlet of Lakes Nipissing had been raised sufficiently above the level of the St. Clair outlet, the present system of drainage was inaugurated and the Great Lakes assumed their present general features. The field studies of a number of individuals have shown that this uplift began in the southwest and progressed gradually toward the northeast, apparently following the release of the land from the load of ice. The hinge line for each of the lacustrine stages has thus moved to the northeast and has slightly shifted its direction. In the Detroit region the beaches are approximately horizontal, but just beyond the northern boundary of the district they begin to rise steadily toward the north and east, the Grassmere beach as it is traced into the "thumb" showing the phenomenon of "splitting." The investigations of Gilbert on the lake gages and the botanical studies of Mosely in the vicinity of Sandusky seem to have demonstrated that this differential movement of the region is still in progress, and that the entire Great Lake region is being slowly canted toward the southwest. The result is that the water, relatively to the land, is slowly rising about the western end of Lake Erie, the water of Detroit River is becoming correspondingly deeper, and the tributary streams are growing still more sluggish about their mouths.

DEVELOPMENT OF PRESENT DRAINAGE.

The retreat of the ice front from the Fort Wayne moraine and the recession of the glacial waters from southeastern Michigan exposed the morainic belt in the northwest corner of the quadrangle and the flat till plain gently sloping southeastward. This uncovering of the higher parts of the area first brought the headwaters of the various drainage streams into existence long before the trunk streams were formed and imposed on the region a rather unique history. The streams were at first short, straight, unbranched, and more or less parallel. With each successive fall of the lake waters the streams were lengthened correspondingly in the direction of their mouths, and with increasing age they developed branches, incised their channels, and finally developed meanders.

Following the direction of the slope the natural direction of flow for all the streams was to the southeast, but numerous deflections occurred because of morainic and beach ridges and delta deposits. Owing to the peculiar, oscillatory nature of the lake recession, the streams crossing the area were alternately active and sluggish in their lower courses and built up a succession of flood plains and delta terraces. As they approach Detroit River, the younger condition of the streams is indicated by their relatively straight courses and few branches. Over the loose-textured soils of the deltas and broader beaches few tributaries have developed, the water soaking through to the underlying clay and giving rise to seepage springs along the banks of the deeper valleys.

When the northwestern part of the district, lying above the level of the Maumee beaches, is compared with the southeastern part as to drainage development, the contrast is so marked as to indicate that the period of time from the disappearance of the ice from that part of the area down to the establishment of the present Great Lakes, or even down to Nipissing time, may be greater than the time since. Taylor's studies of the cutting of the Niagara gorge[1] seem to offer more conclusive evidence of the brevity of post-Nipissing time and therefore of the life of the present Detroit River.

All the main drainage streams which cross the area and flow into Lake St. Clair, Detroit River, and Lake Erie exhibit markedly the phenomenon of drowning. It was noted previously that during the existence of both Lakes Algonquin and Nipissing the drainage was several times deflected from St. Clair River. The water in this river was lowered in consequence and the tributary streams flowed to a lower base-level. As a result these streams cut their beds in the vicinity of their mouths from 15 to 20 feet lower than would be possible in their present sluggish condition. With the reestablishment each time of the St. Clair-Detroit drainage, the level rose, submerged the former banks, produced slack water for several miles, and greatly extended the marsh area in the vicinity. As just noted, the same result has been still further emphasized by the differential crustal movements of the region.

RECENT EROSION AND DEPOSITION.

The erosion and deposition referable to the Recent epoch are in nowise to be separated from that of the closing Pleistocene in this region. The deepening and broadening of the valleys then begun and well started has continued to the present day. The greatest amount of cutting has been done along the middle courses of the streams, where the combined volume and velocity attain their greatest effectiveness. In the upper stretches the velocity is greatest but the volume is lacking; in the lower stretches the volume is at maximum but the velocity is greatly reduced. Studies by Jefferson on the Rouge and the Huron have shown that they are cutting into the till from $2\frac{1}{2}$ to 3 times as much on their right as on their left banks. This may be caused by the rotation of the earth from west to east, or it may be due to the general canting of the Lake region, which also would have a tendency to throw the water of the streams against their western banks.

As the result of periodic overflow the streams are adding each time a thin deposit of silt to their flood plains. As these are slowly built to higher levels and the bed itself is lowered, the flood plains are covered only during exceptionally high stages of the streams and are eventually abandoned. By meandering and undercutting these flood plains may be in large part destroyed and new ones started at lower levels. The broad flood plains of the Huron and of the various branches of the Rouge show abundant evidence of channel straightening by means of "cut-offs," which give rise to oxbow lakes or crescentic patches of marsh. In the vicinity of Flat Rock and between it and Rockwood the Huron has made some slight shifts in the location of its valley on the floor of the flat and low-lying lake bottom. Between Rockwood and South Rockwood there was in comparatively recent time a small island in the river, caused by the deflection of a part of the water to the north around a low till knoll, possibly part of the Grosse Isle moraine. The southern channel was deepened more rapidly than the northern and eventually drew to itself the entire flow of the river.

Owing to the youthful condition of the streams along the eastern margin of the area, there has been little meandering and but little in the way of stream capture. The northern branch of Swan Creek parallels Huron River for a distance of 23 miles at a considerably higher level. Throughout most of this distance the two streams are only 2 to 4 miles apart, the divide at one place (a mile west of Willow) being less than a quarter of a mile wide. An interesting case of stream capture lies just beyond the western limits of the Romulus quadrangle (NW. $\frac{1}{4}$ sec. 19, Van Buren Township), where the Huron has recently captured Oak Run, a tributary of Willow Run. The dendritic drainage that characterizes the Wayne quadrangle

[1] Taylor, F. B., U. S. Geol. Survey Geol. Atlas, Niagara folio (No. 190), 1913.

indicates that much of it has taken shape in late Pleistocene and Recent time.

So far as may be judged from the hydrographic charts of the United States Coast and Geodetic Survey the modern streams have accomplished but little in the way of delta formation. The largest deposit of this nature has been made by Huron River at the west end of Lake Erie and appears to cover only a few square miles. It is a matter of surprise that the drowned mouths of the various streams have not more fully silted up their submerged channels.

From Milk River Point southward along the western shore of Lake St. Clair the waves have proved destructive rather than constructive and many feet of shore have been thus removed within the period of civilized occupation. During this cutting into the eastern flank of the Emmet moraine the bowlders have been concentrated along the water line, a somewhat effective breakwater has resulted, and the wave action has been correspondingly checked. (See Pl. VII.) The swift current of Detroit River has also eaten into the banks of the mainland and of the islands. The wave action has been ineffective in producing beaches in the protected places, and the strip of Erie shore that lies within the district consists of extensive marsh, grown up with vegetation, along the outer margin of which the lake waves have thrown up a low sand ridge.

FORMATION OF ORGANIC DEPOSITS.

Peat.—Small areas having poor drainage because of the topography or those in which the ground water lay near the surface furnished conditions favorable for a rank growth of vegetation of certain water-loving societies, such as rushes, sedges, grasses, mosses, and algae. When the amount of water was sufficient, decay was in part prevented and the partly decomposed organic matter accumulated as beds of peat, containing more or less of impurity. Floating plants produced such formations also in water too deep for plants to secure a foothold on the bottom, and when time proved sufficient peat beds of considerable thickness resulted. As time is an essential factor in the formation of extensive peat beds and as the glacial waters so recently occupied the greater part of the district, this area affords comparatively little of that material. Deposits of peat have already been described and located under the heading "Stratigraphy."

Attracted by the rank vegetation of these bogs the American mastodon was occasionally induced to venture too far from the solid margin, becoming hopelessly mired because of his tremendous weight and leaving his bones and ivory tusks embedded in the peat. The remains of one of these creatures were found in 1893 on the farm of Albert Darling, Sumpter Township, and were transferred to the museum of the University of Michigan. In the fall of 1909, while excavating a county ditch on the farm of J. H. Vreeland (NW. ¼ NE. ¼ sec. 12, Monguagon Township) the workmen discovered a similar skeleton, with the teeth in an unusually fine state of preservation.

Marl.—Associated with the beds of peat and muck and generally beneath them there often occurs a stratum of a white, ashy-looking soil known as bog lime or marl. This material consists in large part of calcium carbonate, which was originally secreted from the lake water by the stems and leaves of certain submerged plants (largely *Chara*) and after their decay found its way to the bottom. Not infrequently the shells of modern water mollusks were incorporated with the finer deposit, sometimes to such an extent as to give rise to a "shell marl." For reasons mentioned above in connection with the peat this district furnishes no such extensive deposits of marl as those found in the physiographically older areas just to the west and north.

Bog iron ore.—Deposits of red and yellow ocher, of sufficient size to be of economic importance, are referred to under the heading "Stratigraphy." These represent swamp deposits of iron oxide, transported through the agency of plants and finally precipitated along with impurities of sand and alumina. Iron-bearing minerals contained in the soil furnished the original supply; their decay led to the formation of iron oxide; and in the presence of the carbon dioxide gas resulting from plant decay the oxide was converted into the very soluble iron sulphate ($FeSO_4$) or into the iron carbonate ($FeCO_3$), which is somewhat soluble, especially in water containing carbon dioxide gas. In these forms the iron was transported to the swamp, where the carbonate or sulphate was decomposed and a compound of iron, oxygen, and water was formed, known as hydrous ferric oxide or limonite ($2Fe_2O_3+3H_2O$).

ATMOSPHERIC CHANGES.

The exposure to which the land surface has been subjected has resulted in only insignificant changes in the composition of the soil. The clay has been leached of its calcium carbonate to a depth of only a few inches, and a slight concentration of this ingredient has taken place in the subsoil. The oxidation of the iron has locally reddened the clay but ordinarily has simply caused it to assume a yellowish-brown color, in places to depths of 15 to 25 feet but ordinarily much less.

General surface erosion has been small, even in the more steeply sloped morainic areas, probably as the result of the protective effects of the vegetation. Locally erosion has become noticeable as the result of the cultivation of the soil, particularly on the slopes. In the vicinity of the old shore lines vegetation has not been supported sufficient in quantity or of the proper type to anchor the loose soil and the wind has shifted the sand considerably, thus modifying the topography and also the character of the soil. Dune ridges thus formed have obscured some of the sandier beaches and have connected them in such a way that it is often difficult to complete their mapping.

RELATION OF SETTLEMENT TO TOPOGRAPHY.

The peculiar topography of the district has had a marked influence on its settlement and development. The beach and dune ridges and the stream courses determined the location of the Indian trails, many of which were used as roads by the white settlers, and their locations were thus preserved. Owing to poor drainage the development of much of the area was greatly retarded, but the higher and better-drained ground was easily cultivated, and the sand and gravel ridges furnished desirable sites for settlement. The French settlements were along the shores of the lakes and of Detroit River, and the farms ran back at right angles to the shore. The cabins faced the water, and the roads paralleled the boundaries of the claims.

The location of the early settlement at Detroit was determined by the topography. The moraine reaches the river at that point and there is well-drained land on both banks. Cadillac chose the highest available ground, which overlooked the narrowest part of the river and where there were no obstructing islands, as the site for Fort Pontchartrain, and about it the new settlement grew up. The place is said to have been the site of a permanent Indian village named Yondotiga, or "Great Village." As the settlement expanded into the city of Detroit, the main streets were laid out either parallel or perpendicular to the river and the present street plan of the city was thus developed.

Trenton and the villages along the shore of Lake St. Clair are on morainic ridges adjacent to the river and lake; Northville, Plymouth, Belleville, New Boston, and Flat Rock are situated where water power is available; and Rockwood is at the head of slack-water navigation on Huron River.

ECONOMIC GEOLOGY.

MINERAL RESOURCES.

The mineral resources of the district are entirely nonmetallic, but they are diverse and taken as a whole are of great commercial value. The most important are clay, limestone, and rock salt, which furnish the raw materials for a number of large industries. Of less importance are building sand, brick sand, glass sand, building stone, gravel, and road metal.

CLAY.

The clay industry in the vicinity of Detroit has for many years been centered about Leesville and Springwells and has shifted largely from the former to the latter district, where the deposits of clay are thicker. The clay has been utilized in the manufacture of common red brick by about 25 establishments, a few of which are in operation the entire year. The manufacture of pressed brick was attempted but was given up when it was found that the clay is not well adapted to that purpose. Draintile is made at only one plant in the district, that of J. C. McDonald & Son, on Warren Avenue. Many kinds of artistic interlocking roofing tile are manufactured by the Detroit Roofing Tile Co., and a small flowerpot factory is in operation. Common brick and draintile have also been made for years at South Rockwood and Dearborn and at several other places in the district, where small deposits of lacustrine or alluvial clay have been available. Owing to the presence in the till of pebbles, particularly of limestone, no attempt has been made thus far to utilize this extensive deposit.

SAND, GRAVEL, AND BOWLDERS.

The broad belts of the Wayne, Elkton, and Grassmere beaches are capable of supplying great quantities of more or less pure yellow to reddish sand. The most accessible deposits are those near Sand Hill and Romulus, but less extensive ones can be found along any of the steam and electric roads leading from Detroit. The Maumee, Whittlesey, and Warren beaches contain patches of poorly assorted sharper gray sand, interstratified with gravel, which necessitates screening.

The best and most extensive gravel deposits constitute the kame mounds and ridges associated with the Defiance moraine in the northwest corner of the quadrangle. (See Pls. IX and X.) The pebbles are generally well sorted, rounded to subangular, and ordinarily 40 to 50 per cent of them are limestone or dolomite. The beach and delta gravels available in the nonmorainic areas are not so well sorted, include more sand, and contain a somewhat lower percentage of limestone and dolomite and a higher percentage of quartzite and crystalline rocks.

The cobbles and bowlders occur in three fairly well defined and continuous belts. More than 90 per cent of the material consists of quartzite, conglomerate, and crystalline rocks, all of foreign origin. For many years this class of material has been utilized locally in rough construction work. When crushed the bowlders form a much more durable road metal than gravel or crushed limestone and dolomite, but they are not abundant enough at any locality to make them of economic importance. Some that would take a good polish have been cut into dressed stone.

GLASS AND SCOURING SAND.

The Sylvania sandstone has all the qualities required for the manufacture of a high grade of glass: it is finely and uniformly grained, runs very high in silica, is free from impurities, and is exceedingly incoherent. Much of it can be disintegrated by the stream from a hose and pumped from the pit in suspension. Mixed with fusible bases it melts readily and yields a glass free from color. It is also used for sanding surfaces and for scouring. It has been mined and marketed for a number of years at the pit of the National Silica Co., 7 miles northwest of Monroe. Just east of Rockwood, in the southeast corner of Wayne County, a pit opened through 15 to 18 feet of till has reached sand, 75 feet of which is said to be available. Samples of the sand, after washing, were analyzed with the following results:

Composition of sand from Sylvania sandstone, Rockwood pit.

[J. E. Clark, Detroit, analyst.]

Silica (SiO_2)	99.70
Calcium carbonate ($CaCO_3$)	.08
Magnesium carbonate ($MgCO_3$)	.22
	100.00

Composition of sand from Sylvania sandstone, Monroe County pit.

[Harry S. Reed, Detroit, analyst.]

Silica (SiO_2)	99.73
Alumina (Al_2O_3)	.03
Ferric oxide (Fe_2O_3)	.18
Calcium oxide (CaO)	None.
Magnesium oxide (MgO)	None.
Loss on ignition	.06
	100.00

An attempt has been made to excavate this sand by simple pumping through a 6-inch pipe located alongside the Grand Trunk Railway near Rockwood. The well passes through 15 feet of dolomite and 15 feet of drift and penetrates 92 feet of sand without reaching the base. The sand is brought up in suspension by a stream of water under 60 pounds pressure, after which it is dried and screened. In the Oakwood salt shaft the Sylvania sandstone was reached at a depth of 422 feet and has a thickness of 113 feet. Much of it could be removed by the hoisting machinery used for the salt.

LIMESTONE AND DOLOMITE.

The Dundee limestone, well exposed at the Sibley quarry just north of Trenton, and the Detroit River dolomite, which reaches the surface in the lower Detroit River region, furnish great quantities of rock. The Anderdon limestone member of the Detroit River dolomite, which here underlies the Dundee, is just being exposed in the deeper parts of the Sibley quarry and will further augment the supply of high-grade limestone.

Building stone.—Solid blocks of bluish-gray limestone of almost any desired size may be obtained from the lower strata in the Sibley quarry. The drab magnesian strata of the Detroit River dolomite are not so massively bedded and so free from joints as the Dundee, yet large blocks are available. In the course of 30 to 50 years of exposure this rock takes on a mealy coating, weathering more rapidly than either limestone or good sandstone. The present popularity of cement for many sorts of work has greatly reduced the demand for this stone.

Broken stone.—The dolomite and the less pure varieties of limestone are crushed for road metal, ballast rock, and concrete. The refuse from the Dundee limestone at the Sibley quarry, especially the cherty strata, which have no other value, is fully utilized in this way. The Hall quarry, just west of Gibraltar, and the Patrick quarry, on Grosse Isle, were operated entirely for the production of crushed dolomite, but they have ceased operations and are now filled with water.

Lime.—The pure limestones of the Dundee and of the Anderdon member of the Detroit River dolomite furnish a high-grade quick-slaking lime, and several kilns of the continuous type were in operation at the Sibley quarry. The soda-ash and alkali establishments at Delray, Ford City, and Wyandotte burn lime from limestone obtained either from the Sibley quarry or from near Alpena. The Detroit River dolomite yields a poorer grade of lime which slakes more slowly, develops less heat, and requires more time for setting Lime of this type was formerly manufactured at Flat Rock.

Cement.—Owing to the supposed similarity of the Detroit River dolomite to the so-called hydraulic limestones of New York hope was entertained that it would prove equally valuable for the manufacture of hydraulic cement, but analyses and experiments thus far made do not hold out much promise that the hope will be realized. Material from selected beds of the Sibley quarry could doubtless be combined with the lake clays of the Detroit district for the manufacture of Portland cement.

Sand-lime brick.—Two plants for the manufacture of sand-lime brick are in operation in the district, one near the Sibley quarry and the other in Detroit. The Sibley Brick Co. has been operating such a plant since 1904, using lime of its own manufacture and sand sucked from the bed of Lake Erie near Gibraltar.

SALT.

Rock salt.—The thick beds of salt in the Salina formation are capable of yielding unlimited quantities of rock salt of a good grade. Mining was begun in 1910 at Oakwood by sinking a deep shaft (see fig. 19), which reached a 20-foot bed of salt at a depth of 1,020 feet. In a boring at the bottom of the shaft, at a depth of 1,110 feet, a 30-foot deposit of salt was entered which proved to be regularly and distinctly stratified in beds ranging in thickness from 1 inch to 2 feet, separated by thin layers of salt discolored by dolomitic sediment and shale. The salt is loosened by blasting, shoveled into tramcars, and hoisted to the surface, where it is crushed and screened into the several marketable sizes. The plant is now operated by the International Salt Co. by means of about 2 miles of underground track.

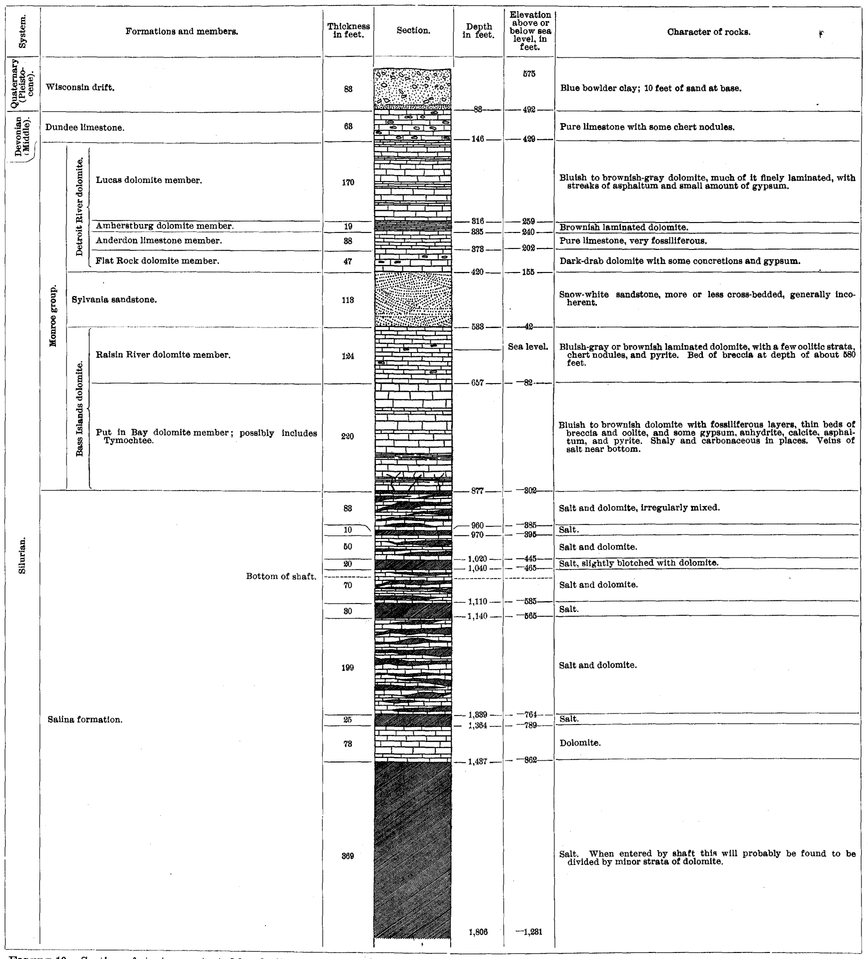


FIGURE 19.—Section of strata penetrated by shaft and boring at the Oakwood salt mine, showing the workable beds of rock salt in the Salina formation.
Scale: 1 inch=200 feet.

The product is utilized mainly for salting stock, for the preservation of meat, fish, and hides, and for general refrigeration. The following grades are recognized:

Lumps—Coarse fragments.
No. 2—Passing $\frac{3}{8}$-inch mesh, caught on $\frac{1}{4}$-inch mesh.
No. 1—Passing $\frac{1}{4}$-inch mesh, caught on $\frac{3}{16}$-inch mesh.
"C. C."—Coarse chemical; passing $\frac{3}{16}$-inch mesh, caught on $\frac{1}{8}$-inch mesh.
"F. C."—Fine chemical; passing $\frac{1}{8}$-inch mesh, caught on $\frac{1}{16}$-inch mesh.
"Dust"—Everything passing $\frac{1}{16}$-inch mesh.

So far the strata have not yielded an appreciable amount of potassium salts.

Brine.—Although the Berea, Dundee, Detroit River, and Bass Islands formations yield natural brines their composition is such as to render them unfit for the manufacture of salt. A brine is made at many points along Detroit River from Delray to Wyandotte by forcing the river water through borings into the Salina strata and pumping it out again. This brine is then evaporated at the several plants by the direct, grainer, or vacuum method and the several grades of salt are obtained. A list of the companies having plants in this district and their approximate locations is given in figure 20.

A more important industry in the district than the manufacture of salt, and one based on both the brines and the high-grade limestone of the Dundee formation, is the manufacture of soda ash, baking soda, caustic soda, and bleaching powder. The principal plants are at Delray, Ford City, and Wyandotte. (See fig. 20.)

The composition of the artificial brines as they come from the wells is shown in the accompanying table:

Analyses of brines from Michigan salt wells.[a]
[R. F. Gardner and A. R. Merz, analysts.]

	71[b]	72[c]	73	74	75	76	77	78	79	80	81
Potassium	Trace.	Trace.	0.1	0.1	0.2	0.1	0.2	Trace.	1.4	2.4	Trace.
Sodium	114.5	119.2	113.7	113.4	112.8	114.4	113.4	120.6	78.2	123.3	121.3
Calcium	.6	1.4	1.8	2.1	1.9	1.8	1.2	.8	17.8	.8	.6
Magnesium	1.0	.4	.4	.4	.7	.8	.6	Trace.	12.8	Trace.	Trace.
Chlorine	175.0	185.0	176.9	176.9	175.9	178.6	178.0	183.8	182.1	189.3	185.2
Sulphuric anhydride	2.2	2.8	3.3	3.7	3.2	4.0	.8	4.4	4.2	4.0	3.4
Bromine	Trace.	Trace.					Trace.	Trace.	1.7	.9	None.
Conventional combinations.											
Potassium chloride	Trace.	Trace.	.2	.2	.4	.2	.4	Trace.	2.7	4.6	Trace.
Sodium chloride	290.6	302.6	288.6	287.8	285.0	290.4	288.1	300.9	198.5	306.4	308.8
Calcium chloride	Trace.	.6	1.1	1.7	1.7	.3	2.8	2.2	40.1	2.2	1.7
Magnesium chloride	3.6	1.6	1.6	1.6	2.7	3.1	2.4	Trace.	45.5	Trace.	Trace.
Calcium sulphate	3.1	4.0	4.7	5.2	4.5	5.7	1.1	Trace.	7.5	Trace.	Trace.
Magnesium bromide	Trace.	Trace.					Trace.	Trace.	3.9		None.
Sodium bromide											1.6

[a] Michigan Geol. and Biol. Survey Pub. 15, Geol. Ser. 12, p. 89, 1914. See also Turrentine, J. W., Composition of the salines of the United States: Jour. Indust. and Eng. Chemistry, vol. 4, No. 11, 1912.
[b] Delray Salt Co.
[c] Michigan Alkali Co.

A report on the salt deposits and industry in Michigan has recently been issued by the Michigan Geological Survey.[1]

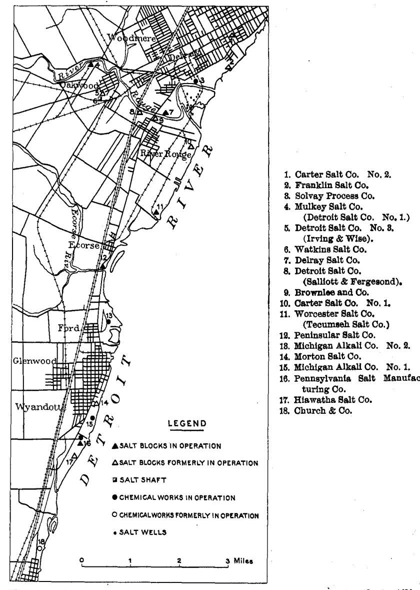


FIGURE 20.—Sketch map showing the location of the industries that utilize the salt deposits near Detroit River.
Salt wells at plants are not separately shown.

PIGMENTS.

Deposits of red and yellow ocher of sufficient size to be economically important occur in Sumpter Township, and a company has been organized to develop them. They represent swamp deposits of iron oxide which was originally scattered through the soil and has been transported and concentrated by running water. Mixed with oil this material constitutes a low-grade paint. The known deposits have been described under "Stratigraphy" (p. 12).

ABRASIVE MATERIALS.

Two abrasive materials of the same general type but of widely different geologic age are found in the district. When examined under the microscope much of the Sylvania sandstone is seen to have been secondarily enlarged; crystal faces have formed over the well-rounded granules and have given them very sharp edges and points. It is this condition of the sand that causes its sparkling appearance as the light is reflected from the tiny facets. Such sand is particularly well adapted to serve as an abrasive. It outcrops along Raisin River in Monroe County and it has been used to some extent for scouring and on match boxes. It should produce an excellent sandpaper.

An exceedingly fine grayish sand obtained from the Huron Valley near Belleville has been placed on the market as a metal polish. The individual grains, when spread thinly over a dark surface, can just be detected with the naked eye or they can be felt when rubbed between the fingers. Under the microscope they are seen to be sharply angular grains consisting largely of quartz.

[1] Cook, C. W., The brine and salt deposits of Michigan: Michigan Geol. and Biol. Survey Pub. 15, Geol. Ser. 12, 1914.

PEAT.

No extensive beds of peat were formed in the area. The swamps described under "Topography" furnish some peat, but the deposits are probably thin and at present are commercially unimportant. The production of gas from peat is rendered possible by distilling the partly dried product in a retort supplied with a certain amount of air and superheated steam. The by-product, ammonium sulphate, is a valuable fertilizer. The use of fibrous peat as "litter" in bedding stock is strongly recommended. When used as an absorbent about barnyards the peat becomes even more valuable to the farmer than the leached manure. At the nurseries in Monroe County the fresh sphagnum moss, obtainable from peat bogs, is used for packing the roots of trees for shipment.

NATURAL GAS.

Much money has been spent in searching for oil and gas near Detroit River with very meager direct returns, though the borings have afforded a great deal of knowledge regarding the geologic structure of the district, its water-bearing strata, and its deposits of rock salt. The positions of the gas wells are shown on the areal-geology maps. There seems little justification for further heavy expenditures in this search, though the heavy flows of "pocket gas" from many places in the Antrim shale will probably continue to arouse false hopes and to stimulate unwise expenditures. If this pocket gas, which at times gives pressures exceeding 100 pounds to the square inch, were confined it could be utilized. It has, in fact, been used for years in sec. 25, Southfield Township, where the original pressure was 37 pounds to the square inch. The supply from each well will be exhausted sooner or later, but new wells can be put down or the old ones can be deepened.

In Greenfield Township lampblack was at one time manufactured from this gas, but the experiment was not particularly successful and was given up.

As some fragments of the Antrim shale burn with flame they are sometimes mistaken for coal. Efforts have been made to mine them near Belleville. This great mass of shale contains quantities of gas, oil, and other combustibles, which may be recovered by distillation but which are not yet sufficiently valuable to justify the expense of the process. In view of the increasing price of gasoline and the possible exhaustion of the available supply of crude oil from which it is now made, the prospecting of these shales would seem to be justified.

WATER RESOURCES.

SURFACE WATER.

Lakes.—In striking contrast with the adjacent territory on the north and west the Detroit district is deficient in ponds and lakes, having, except for small bayous on flood plains, only one natural pond, Yerkes Lake, in sec. 2, Northville Township, which discharges at high stages into Middle Rouge River. It was rejected as a water supply for Northville because of its low altitude.

Water pumped from Lake St. Clair by windmills is used by many residents of Grosse Pointe Township and is supplied to the village of Grosse Pointe Farms through an intake extending, because of the shallowness of the water, about 1¾ miles from shore. The water flows by gravity to a settling basin, from which it is pumped into the mains.

Streams.—Aside from Detroit River the streams are little used as sources of water, except for live stock and for irrigating truck farms, the irregular flow, frequent high turbidity, and liability to pollution of most of them preventing their more extensive use. The water of the Lower Rouge is used in the dye processes at the Arno Mills in Dearborn, and the main branch for a time supplied water to the boilers of the power plant of the interurban electric line. Water from the Rouge is used also in boilers, for sprinkling, for flushing sewers, and for fire protection in the Wayne County Home at Eloise.

Detroit River supplies Detroit and many of the nearer suburbs, to which the mains have been extended. The water is taken from the river at the head of Belle Isle through a recently constructed tunnel and is distributed by pumps from a central plant in the eastern part of the city. In 1898 a separate high-pressure system was installed in order to obtain more adequate fire protection. Below Detroit, the city of Wyandotte, the villages of Ecorse and Ford, and many residences on Grosse Isle are also supplied from Detroit River.

The turbidity of the water of Detroit River is low, except just after heavy storms, as Lake St. Clair serves as a great settling basin. The results of analyses, given in the following table, indicate that, owing to its low content of mineral matter, the water is adapted to a great variety of uses in manufacturing. Though the samples analyzed were taken from midstream in St. Clair River at Port Huron, the drainage between that point and Detroit does not essentially alter the chemical composition of the water of Detroit River, which is a calcium carbonate water of low mineral content, good for boiler use and capable of forming in boilers only a small amount of rather soft scale.

Results of mineral analyses of water from Lake Huron at Port Huron, Mich.[a]

[Parts per million, unless otherwise stated.]

Date (1906-7).	Turbidity.	Suspended matter.	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Total dissolved solids.	Mean gage height (feet).[b]
Sept. 21	1		13	0.02	24	6.4	3.5	3.4	97	4.8	0.30	2.5	108	581.13
Oct. 21	2		8.7	.10	24	6.3	3.7	3.6	96	6.2	.25	2.5	105	580.87
Nov. 21	Tr.		8.0	.05	24	6.7	3.0	.0	100	5.6	.4	2.6	101	580.68
Dec. 21	Tr.		12	.05	23	6.7	3.5	.0	103	6.6	.3	3.1	106	580.65
Jan. 21			12	.03	23	7.1	5.8	.0	99	6.7	.4	2.5	108	580.65
Mar. 21			14	.03	23	7.2	4.7	1.2	101	6.7	.3	2.5	109	580.68
Apr. 21			14	.04	24	7.7	5.1	Tr.	106	6.0	.45	2.6	110	580.90
May 21			14	.05	25	7.6	5.9	2.4	102	7.3	.4	2.8	116	581.08
June 21			8.5	.04	24	7.5	4.7	5.3	96	6.4	.45	2.8	105	581.39
Mean	Tr.	Tr.	12	.04	24	7.0	4.4	1.8	100	6.2	.4	2.6	108	
Percentage of anhydrous residue			11.1	[c].0	22.3	6.5	4.1	47.4		5.8	.4	2.4		

[a] Analyses by R. B. Dole and M. G. Roberts, published in The quality of surface waters in the United States, Part I, Analyses of waters east of the one hundredth meridian: U. S. Geol. Survey Water-Supply Paper 236, p. 65, 1909.
[b] Gaging station at Harbor Beach, Mich., 60 miles above sampling point.
[c] Fe_2O_3.

The waterways between Lake Huron and Detroit bear enormous shipping during the open season and receive more or less pollution, not only from boats but also from the settlements along their banks in Michigan and Ontario. The results of bacteriologic examinations, by the International Joint Commission, of serial samples from Detroit River above the waterworks intake of Detroit showed that river water was an unsafe source of supply without careful treatment, and the commission expressed the opinion that the application of calcium hypochlorite in the quantities or by the method in vogue in Detroit during the investigation was not adequate.[1] Samples from several cross sections in the river from the tunnel of the Michigan Central Railroad to the mouth of the river showed that the water was grossly polluted and unfit as a source of supply, and the commission expressed the opinion that such raw water would impose an unreasonable responsibility on any known method of purification, even with most careful supervision.

The waters of the smaller streams in the district yield much larger contents of mineral matter than Detroit River, as the following results of analyses indicate:

Mineral content of river waters near Detroit.

[Parts per million.]

	1	2	3
Total solids	390	828	430
Organic and volatile matter	192	96	150
Total hardness as $CaCO_3$	168		
Calcium (Ca)	38		
Magnesium (Mg)	20		
Bicarbonate radicle (HCO_3)	150		
Sulphate radicle (SO_4)	51		
Chlorine (Cl)	9	37	5

1. Huron River at Ann Arbor, July, 1911. R. W. Pryor, analyst.
2. Middle Branch of River Rouge, L. M. Gelston, analyst.
3. Lower Branch of River Rouge, J. E. Clarke, analyst.

Water power has been used for local mills at several places along Middle and Upper Rouge and Huron rivers. The flow of the streams, however, is irregular and is much reduced in the summer, so that the water power has to be supplemented by steam if the plant is to be operated continuously. The heavy spring floods, often bringing ice with them, occasionally prove destructive to the dams. A scheme to remedy these difficulties is now under consideration, so far as Huron River is concerned, by establishing in the region of its chain of lakes a great storage reservoir from which the water can be let out gradually during the year. The absence of such natural basins in connection with the upper branches of the Rouge would prevent the carrying out of any such scheme for conserving the surplus flow of that system. Under favorable conditions 360 horsepower can be developed on the Middle and Upper Rouge at Northville, Plymouth, Pikes Peak, and Southfield, and near Redford and Dearborn. From Rawsonville, at the west side of Wayne County, to Lake Erie the fall of Huron River is approximately 75 feet, or, measured along the valley, an average of 3 feet to the mile. With high banks favorable for ponding and an average mean flow of 500 to 550 feet per second considerable energy is here still available, only 22 feet of the fall being utilized. Power is developed at Belleville, New Boston, and Flat Rock, in the Romulus quadrangle, with a maximum capacity under present conditions of 625 horsepower.

GROUND WATER.

WATER FROM LAKE AND RIVER DEPOSITS.

Beach and delta deposits of sand and gravel, with associated dunes, cover many square miles of the district. Loose and porous except when frozen, with in places as much as 30 per cent of their volume consisting of pore space, they readily absorb large quantities of rain water, which sinks through the pervious deposits until it reaches the underlying clay, where it is held in basins or slowly works its way along the clay slope. Dug wells 10 to 15 feet deep reach the level of this ground water and obtain water much harder than that of Detroit River. The supply is ordinarily sufficient and in some wells abundant, but it fluctuates greatly with the season and after prolonged drought may entirely fail. It is generally necessary to sink to the clay in order to find water and it is often desirable to dig a short distance into the clay in order to form a reservoir. The lake deposits of clay that were laid down in deeper and quieter water include no water horizons and are very retentive of whatever water they may contain. In areas underlain by them water must be procured either from overlying looser sand or from the drift or bedrock beneath them. The temperature of the water of the shallow wells fluctuates with the season much more than that of the deeper wells. This type of well is obtained with little difficulty and expense but is especially liable to contamination, and the material from which the water is drawn is not always an effective filter.

About the bases of the sand dunes and at places where the beach and delta deposits are cut by streams water oozes out along the line of contact with the clay substratum and gives rise to "seepage springs." The flow of some is slight and simply moistens the surface, but that of others is concentrated and abundant. Most of the springs of this type are along the banks of Huron and Rouge rivers and some of them are utilized by the farmers, the water being lifted into tanks by hydraulic rams. The Wayne County Home, at Eloise, obtains its supply for drinking and kitchen use from a large dune half a mile to the south, the water being collected in small reservoirs and flowing by gravity through pipes. Flowing somewhat freely underground and generally at a distance from dwellings the water of such springs is less liable to contamination than that of shallow wells, although the springs themselves may become contaminated and should be carefully protected.

WATER FROM GLACIAL DEPOSITS.

Nonflowing wells.—The glacial clays yield practically no supply but are valuable in confining the water to the intercalated beds of sand and gravel that are fairly common in the drift sheets. The distribution of the intercalated beds, however, is so irregular that search for well water in them is uncertain and often expensive, particularly in northeastern Van Buren, northwestern Romulus, and certain parts of Dearborn townships. In the saturated sand and gravel beds lying below impervious clay beds the water is generally under pressure and therefore rises in wells. These wells, whose distribution is shown on the artesian-water map on the sheet of special maps, range in depth from less than 20 to more than 100 feet, 60 to 75 feet being common depths. Many of the shallower wells are dug and lined with brick or stone; the deeper ones are driven, drilled, or bored. The deepest nonflowing wells are in northeastern Van Buren, northern Canton, northern Hamtramck, and southwestern Grosse Pointe townships, the maximum depth being 182 feet. Owing to the nearness of the bedrock to the surface in Monguagon and Brownstown townships the drift wells there are shallow and derive their water generally from a bed of gravel lying upon the bedrock.

Water from strata near bedrock is likely to be more highly mineralized than that from beach, dune, and delta deposits, although there are exceptions. The mineral matter is in large part derived from the rock, particularly in the belt of salt wells extending northeastward from northeastern Van Buren and southern Canton townships, where some of the wells yield water too salty to be fit for ordinary use. Such wells should be plugged above the salt-bearing bed and water drawn from a higher horizon. If tightly cased the drilled wells are safe from contamination, but if not cased at all or if the casing is too short or is defective they may receive surface drainage and become a source of danger. The increase in head toward the northwest makes it evident that the collecting areas lie in the high morainal districts in that direction.

Flowing wells.—Two discontinuous belts in which flowing wells occur cross the district, as shown on the artesian-water map on the sheet of special maps, and are the continuation of belts in Monroe and Washtenaw counties. One belt, in the Wayne quadrangle, crosses Van Buren, Canton, Plymouth, and Livonia townships, east of the Whittlesey beach. The other lies along the eastern margin of the district, passing from northeastern Exeter and northern Ash, across Huron, Brownstown, Taylor, and Ecorse townships into Springwells Township, where it is interrupted by the Detroit moraine. In the northeast part of Grosse Pointe Township it reappears and continues near the shore across Erin Township. This belt, especially that part of it near Huron River, has suffered great loss of head and volume. Another narrow belt of flowing wells once extended across Huron, Romulus, and Nankin townships, but, owing to the lowering of the head, the wells have practically ceased to flow and the position of the belt is now indicated by wells in which the water rises nearly to the surface.

[1] Progress report of the International Joint Commission in re the pollution of boundary waters, pp. 36-37, 1914.

The pressure in the flowing wells is ordinarily slight and is sufficient to bring the water only a short distance above the surface. The artesian head is shown by lines of equal pressure on the artesian-water map on the sheet of special maps. The yield of the flowing wells can be increased by pumping. The village of Wayne recently sank a well near the center of sec. 33, Nankin Township, to the depth of 120 feet, and obtained from gravel at 63 feet a heavy flow of good water, the pumping test of which indicated an available daily supply of 150,000 gallons.

The artesian waters show considerable range in hardness. Near Denton, in Van Buren Township, they are so soft that cisterns for storing rain water are not needed. In the eastern belt they contain some dissolved mineral matter, especially iron and hydrogen sulphide, and are probably strongly affected by water from the bedrock. In Northville two flowing wells, 190 feet deep, at the United States fish hatchery, yield water at a temperature of 50° so strong in sulphur and iron as to be destructive to both fish and eggs.

The temperature of the water from flowing wells averages about 52° F. and shows but slight annual range. Such wells are valuable to farmers, as they save the cost of pumping, furnish a means of keeping milk cool in summer, and provide relatively warm water for the live stock in winter.

Springs.—The morainal hills in the northwest corner of the district furnish springs of a different type from the so-called seepage springs. In a number of low places about the hills water of practically the same temperature and character as the rest of the water from the drift escapes under considerable pressure and in large volume. Two such springs supply the United States fish hatchery at Northville with an abundant flow at a temperature that was 47° but that is now 48°. The villages of Northville and Plymouth utilize flows from springs 2 to 4 miles distant, the water being brought in by gravity. The supplies are abundant, are of good quality, and give sufficient pressure for fire protection.

WATER FROM THE BEDROCK.

Flowing wells.—The flowing wells drawing from bedrock in the eastern belt mingle their waters with those from the drift and the flow from many of them is strongly mineralized with sulphur and iron compounds and from some is too rank for use. The average temperature, so far as measured, is 51.4° F. The water in most of the wells rises only slightly above the level of the ground, but in a few of them, as at Dearborn and Grosse Isle, it rises 15 to 25 feet above. The available data indicate that the head increases toward the northwest at an average rate, which is about 5.6 feet to the mile across the middle of the district, 3.5 feet to the mile in the Huron River area, and 3 feet to the mile in the Swan Creek area. Although the strata dip to the northwest the water appears to come from that direction, moving up or across the strata rather than down them. The collecting area is probably the drift-covered Thumb Upland, which lies from 900 to 1,200 feet above sea level.

Several deep wells have tapped heavy flows in the lower strata and have furnished information regarding the volume and character of the water and the pressure to which it is subjected. The Swan well, near the south end of Grosse Isle, has a depth of 2,375 feet and flows 3,000 gallons a minute, at an altitude of 597 feet above sea level. In it the strongest flows were encountered at depths of 420 and 450 feet and were fresh, but sulphur water was found at greater depths and imparts a decided odor and taste of sulphur to the whole. The well has been flowing strongly since 1903 with no apparent loss in volume.

In 1905 a strong flow of sulphur water was struck on the Rouge Flats at Dearborn, where limestone was entered at a depth of 108 feet and penetrated to 280 feet. The water rose 30 feet above the mouth of the well, indicating a head of 635 to 640 feet. Its temperature is 52.3°, slightly higher than that in the Swan well. The well is capped, but the casing is leaking. As yet no loss in head is noticeable, which suggests that the pressure is truly hydrostatic and not due to gas, as was originally supposed. All the deep salt wells about the mouth of River Rouge will flow if permitted, yielding sulphurous water.

In the Oakwood salt shaft six noteworthy water horizons were encountered, as follows:

1. Just above bedrock; depth, 83 feet; altitude 493 feet; temperature of water, 52.2° F.
2. In Dundee limestone; depth, 77 to 86 feet; altitude, 490 feet; flow strong; much hydrogen sulphide.
3. In Dundee limestone; depth, 135 feet; altitude, 440 feet; relatively small flow.
4. In porous Lucas dolomite; depth, 155 to 168 feet; altitude, 420 to 407 feet; continued flow to depth of 181 feet; water sulphurous; temperature 49.5° F. at a depth of 180 feet.
5. In Lucas dolomite; depth, 191 feet; altitude, 384 feet; remarkably strong flow from a horizontal opening extending across the shaft; water very sulphurous and having a pressure of 90 pounds to the square inch, causing shaft to fill and overflow in 3 or 4 hours.
6. In Sylvania sandstone, except for a 27-foot stratum of dry, siliceous dolomite; depth, 420 to 533 feet; altitude 155 to 42 feet above sea level; seepage flow of sulphurous water.

The combined flows give a head of 595 feet, about 20 feet above the surface, approximately the same as that of the Swan well. Samples of the water from the shaft were analyzed by the United States Bureau of Mines and the results are shown in the following table. The cold water came probably from between 480 and 533 feet.

Mineral content of water from Oakwood salt shaft, Oakwood, Mich.

[Parts per million. A. C. Fieldner, Bureau of Mines, analyst.]

	Cold water.	Hot water.
Silica (SiO_2)	16	14
Iron (Fe)	8	9
Aluminum (Al)	5	9
Calcium (Ca)	727	927
Magnesium (Mg)	217	310
Sodium (Na) and potassium (K)	502	1,848
Sulphate radicle (SO_4)	1,990	1,937
Chlorine (Cl)	1,117	3,880
Volatile and organic matter	389	988
Total solids at 105° C	4,785	9,520
Hydrogen sulphide (H_2S)	249	48

Nonflowing wells.—In origin and character the water from the wells that are drilled into bedrock but do not flow is essentially the same as that of the flowing wells, the only difference being in their head. The water from the Dundee limestone and the Monroe group always contains a considerable proportion of soluble matter. The two mineral-bath houses on Fort Street, Detroit, use water believed to come from the Dundee limestone. At the plant of the Murphy Power & Ice Co., corner of Wayne and Congress streets, Detroit, four wells were put down to depths of 275 to 300 feet. Rock was struck at 100 to 110 feet, from which a supply of sulphurous water was obtained. A much larger supply was obtained at 170 to 200 feet from dolomite in the Monroe group, the water rising to within 15 feet of the surface (head 580 feet). The temperature of the water was 52° F. Pumping tests from the four wells indicated a supply of 1,000 to 1,200 gallons a minute. A well at the Wayne County Home, at Eloise, which reached a depth of 850 feet and ended in the Monroe group, yielded brine, which was analyzed with the following result:

Mineral content of water from salt well, Eloise, Mich.

[Parts per million. S. P. Duffield, Detroit, analyst.]

Calcium (Ca)	9,715
Magnesium (Mg)	150
Sodium (Na)	25,855
Carbonate radicle (CO_3)	3,970
Sulphate radicle (SO_4)	12,855
Chlorine (Cl)	40,214
Total solids	91,759
Hydrogen sulphide (H_2S)	405

The most promising source for a quantity of fresh water is the Sylvania sandstone, because of its loose texture and freedom from soluble impurities, but the water from it is likely to be mixed with that from the underlying dolomites, as in the Oakwood salt shaft. Water obtained from the Traverse formation is likely to contain salt, although that obtained in the Eloise well was reported to be fresh. The same is true for water from the Berea sandstone, in the northwest corner of the district. Water from a very few wells in bedrock is reported as "soft," but there can be no reasonable expectation of obtaining water even moderately free from mineral matter or hydrogen sulphide in the rock strata of southeastern Michigan.

Springs.—In the lower Huron River and Detroit River areas there are a number of large springs whose waters are impregnated with sulphur, iron, gypsum, salt, and calcium and magnesium carbonates. They are most numerous along Huron River and also northward toward Gibraltar and southward along the shore of Lake Erie. The water is generally too rank for household use or for live stock, although cattle sometimes become accustomed to it. It undoubtedly rises from natural fissures in the bedrock through self-made channels in the thin drift. Where drainage is poor these springs cause marshy conditions and growths of microscopic organisms colored white by sulphur, brown or red by iron, or black by mixture of those two elements.

DECLINE IN VOLUME AND HEAD OF GROUND WATER IN THE LOWER HURON RIVER AREA.

During the last 25 years a marked decline in the volume and head of the artesian-well water in the lower Huron River area and in the adjacent areas on the north and the south has caused great annoyance and much expense to well owners. These conditions are in rather striking contrast to those in the western belt of flowing wells, where the small reduction in flow may be reasonably ascribed to defective casing or to clogging with sand, difficulties easily remedied. In the lower Huron River area, for several miles on both sides of the river, from New Boston to Lake Erie, the wells have ceased to flow and in many of them the water level has dropped several feet below the surface. The loss of head during the last 12 years is from 5 to 10 feet, and in a region where formerly flowing wells could be counted by hundreds scarcely one remains. South of Huron River a careful survey of three former flowing-well districts reveals not a single well in which the water now reaches the level of the general surface, only five in which it continues to flow on the flats, which are 3 to 5 feet below the general surface level. North of the Huron one well still flows, but its yield is greatly reduced.

Although it has extended over a number of years this decline does not appear to have been gradual. In 1904 a marked reduction led to an investigation by the Michigan Geological Survey, the work being undertaken by M. L. Fuller, of the United States Geological Survey. The data gathered for Fuller's report[1] were obtained in the main from Monroe County, adjacent to Huron River, the region north of the river then showing comparatively little shortage. Since then, however, every well at the general level in that region has ceased to flow, some of them as late as August, 1911. Fuller says:

> The general decline which has been going on for many years is probably due to a gradual and far-reaching change of conditions, such as deforesting the land, improvement in surface drainage, etc., but the rapid decline of the last two seasons is doubtless due to local causes, acting with special force in the region in question.

He regarded the flow from the Grosse Isle well and the underdrainage from the Newport quarry as insufficient to have produced the sharp decline noted and ascribed it in the main to the deficient rainfall of 1904, combined with the early frozen condition of the soil in 1903, by which absorption was prevented. The report predicts that a wet year or a succession of wet years would cause a gain in volume and head, except where clogging of the wells had occurred.

The exceptional climatic conditions of 1903 and 1904 have in part passed away but without any apparent relief in the situation. So far as may be judged from the Detroit records precipitation had not become normal by the close of 1912, although the accumulated deficiency was not great. If deficient precipitation, combined with deforestation, better drainage, and soil cultivation, were the cause, it would be expected to affect the western belt of flowing wells also, but this does not appear to have been the case. It seems probable that causes are at work in the Huron River and Swan Creek region that are not operative farther west and northwest. There can be little doubt that the large number of unrestricted flows would eventually bring about a reduction, but this effect should be felt in the upper valley first and should work its way gradually toward the lake, near which the last wells to cease flowing should be found. That these wells also have ceased indicates either that the collecting area for the region has failed to receive the water necessary to maintain the flow or that the water is being drawn off at a lower level. If the first hypothesis be rejected then facts tending to support the second may be taken into consideration.

Fuller has given theoretic reasons for believing that the Grosse Isle well was not responsible for the marked decline in 1904. The farmers of the region, however, are thoroughly convinced that this well is the cause of their trouble. A conference was held between Judge Swan, the owner of the well, and the supervisors of the townships directly interested, but nothing was accomplished in the way of reducing the flow, and the well still pours some 4,300,000 gallons of water a day into Detroit River.

It seems to the writer that this loss may be only one of several factors that have conjointly brought about the decline in well flows in this region. An estimate of the water that has been drawn from the strata during the few years previous to 1912 is as follows:

Estimated average daily withdrawal of underground water in the Huron River and Swan Creek region.

	Gallons.
Livingstone Channel cut (now filled)	12,000,000
Grosse Isle well	4,320,000
Oakwood salt shaft	568,800
Sibley quarry	330,000
Anderdon quarry, Ontario	150,000
Gibraltar quarry (now filled)	144,000
Newport quarry (now filled)	43,300
Rockwood sand pit (no estimate available).	
	17,576,100

This estimate shows that during the four years, up to and including 1912 there was withdrawn daily from the strata an amount of water equal to the entire annual precipitation on an area of 11 square miles at the rate of 33 inches a year. It would, therefore, seem surprising if some reduction of head and volume had not taken place in the region. As the Livingstone Channel and two of the quarries are now filled it seems probable that some return of the former flow may presently be noticed. If the salt shaft were completely jacketed

[1] Leverett, Frank, and others, Flowing wells and municipal water supplies in the southern portion of the Southern Peninsula of Michigan: U. S. Geol. Survey Water-Supply Paper 182, pp. 33–48, 1906. Also Michigan Geol. Survey Ann. Rept., 1904, pp. 7–83, 1905.

and if the waste from the Grosse Isle well were checked, the return might be still more complete, but it can never again equal the original flow before so many tap holes were bored with no attempt whatever at corresponding conservation.

SOILS AND FORESTS.

SOIL TYPES.

Origin of local soils.—The soils and subsoils of the Detroit district may be classed under five heads, four of which are derived directly or indirectly from the bowlder clay or till and the fifth formed by organic agencies. They belong chiefly to the transported type, as distinguished from the sedentary or residual type. Of the varieties distinguished the differences are mainly of texture or degree of fineness of the constituent particles rather than actual differences in mineral composition, and so no sharp lines can be drawn between them.

Clay soils.—The clay soils of the district are of two types—glacial clays, which have been derived directly from the till, and lake or river clays, which have been separated from the till by water, held in suspension, transported, and redeposited under quieter conditions. Both types consist of a great variety of minute mineral particles, which appear under the microscope as fresh and angular. Because of this fine texture they are readily converted into good "heavy" soil, and because of their variety of mineral ingredients they furnish an abundance of plant food.

The glacial clays are found in the rough, morainal areas in the northwestern part of the district, along the eastern margin, and, generally, wherever the clay occupies the surface between the areas of sand and gravel. They are compact, unstratified, and generally pebbly, with scattered bowlders or cobbles embedded in or lying on their surfaces. The uppermost part is rather dark and loose and is to some extent leached. The deeper parts are drab, brown, yellow, or red, gradually passing downward into blue.

The lake clays are delicately laminated, the laminae being separated by exceedingly fine sand grains, and are free from pebbles and bowlders. Because of their manner of deposition their upper surface is flat and their drainage correspondingly poor. Where conditions of moisture are favorable for vegetation the soil from this clay is darker than that from the glacial type.

Sand and gravel soils.—The beaches, deltas, and associated sand dunes consists of sand or gravel or a variable mixture of the two. The sand grains are chiefly quartz, which under the microscope shows some rounding. These soils possess little available plant food and crops on them generally give meager returns. They have the advantage of being light, easily tilled, and readily drained.

Loam.—The belts of sand, where they meet the clay, are generally bordered by narrow strips of loam formed by the mixture of the two. Patches of loam covering a square mile or so are also to be found here and there on the clay areas, and the former lake deltas commonly consist of a sandy loam containing small pebbles. The recognized varieties—clay loam, sandy loam, and gravelly loam—have no sharp lines of division and are adapted to a wide range of plant growth. Agriculturally they are the most valuable soils, as on them may be raised any of the crops grown successfully on either sand or clay.

Silt.—The silt soils are confined to the flood plains of the streams. They are more or less distinctly stratified, dark from organic matter, and loose in structure, and in many places they contain shells of mollusks. From the nature of their occurrence they are of small extent, generally difficult to drain, and subjected to overflow unless protected by dikes. Such strips in this district are generally allowed to grow up in grass and are used for pastures.

Muck and marl.—A prominent characteristic of the morainal parts of the district is the existence of numerous undrained basins in which water may accumulate. Along the old lake beaches, where the sand simply veneers the clay, are many patches of swamp. When the water in the lakes was moderately deep and conditions were otherwise favorable for the growth of *Chara*, beds of calcium carbonate were formed from the accumulation of its remains, producing marl or bog lime. Clay, sand, and some shells are in many places mixed with the finer material, rendering it more or less impure. The known marl deposits of the district are small and commercially unimportant. They have been described under "Stratigraphy" (p. 12).

As the water of the lakes became shallower plants such as rushes, sedges, reed grasses, pond lilies, cat-tails, and arrowheads, of a higher order than the *Chara*, obtained a foothold. Their remains, immersed in water, did not wholly decay and completed the filling of the marsh or pond and prepared the conditions for other sedges and mosses. These, growing above and dying beneath, contributed still further to the organic deposit, and the entire mass gave rise to a bed of peat, or, where clay and sand were mixed with it, of muck. Conditions of time and drainage have not permitted the formation of extensive peat deposits in the district, the largest occupying less than a square mile and being probably of no great thickness. Ordinarily these soils contain from one-fifth to one-fourth sand and about two-thirds organic matter; with increase in sand they grade into black sand and with increase in clay into black clay.

FORESTS AND THEIR RELATIONS TO THE SOILS.

Original forest cover.—From records covering two centuries it is known that parts of the Detroit district formerly supported a luxuriant growth of hardwood timber, that other parts were only sparsely covered with scrubby growth—the "oak openings," and that parts described as "prairie" were presumably without timber, except possibly along the watercourses. Of the original growth only fragments remain, but from these and from the later growth its character may be judged. Coniferous species appear to have been rare, the forest being mainly of the mixed deciduous type, and more than three-fourths of the kinds native to the State were represented. Their fondness for certain types of soil, with its content of food and moisture, has caused the distribution of the native trees across the district to fall into line with the general diagonal trend characteristic of the other natural features. The unpublished studies of F. B. H. Brown have shown that some of these early tree immigrants moved in from the north on the withdrawal of the lake waters and that the later arrivals came in mainly from Ohio and Indiana.

Clay societies.—Under the head of clay "societies" Brown recognizes four types of tree grouping in close relation to the soils of the district. (1) Elm-ash-maple society, which is the most common on the flat clay areas of mainly lacustrine origin. It contains the American elm, red ash, and silver maple, in frequent association with black and white ash, basswood, and cottonwood. (2) Oak-hickory society, which consists of the several species of hickories, of which there are eight, in association with the red oak. It is the chief society in the Monguagon region, where the soil is mainly glacial, and it is also found near the shores of the lakes and along Huron and Rouge rivers where soil conditions permit. (3) Maple-beech society, which is a distinct type made up of a dense growth of hard maple and beech, in nearly equal proportions, with the Kentucky coffee tree and the pawpaw characteristic but rare. In places maple greatly predominates over beech, and in others beech predominates. The till areas of Van Buren, Canton, Plymouth, Livonia, and Redford townships have proved especially favorable for this society, as well as some of the morainal knolls near Detroit River. (4) Walnut society. Although the original black walnut has been completely removed there were once small areas in which this species formed woods of nearly pure growth, especially in the morainal parts of Plymouth and Northville townships. It was abundant and of great size in southeastern Brownstown, in a morainal area a mile wide bordering Huron and Detroit rivers and Lake Erie, where it was associated with Ohio hickory, wild crab, and hornbeam.

Sand societies.—The forest growth of the sand areas is distinct and more varied than that of the clay areas, so that the soil of a region may be predicted from its forest cover. It is roughly estimated that about one-fourth of the district is covered by such sand societies, of which two groupings may be recognized. (1) The pin-oak society. The Wayne beach across the center of the district and the sandy parts of the bed of Lake Wayne are occupied by an assemblage of pin oak, swamp white oak, burr oak, butternut, whitewood, sycamore, cottonwood, aspen, wild plum, pin cherry, wild black cherry, choke cherry, and sassafras. Besides these, which are common, some species from the clay societies, such as the elm, hornbeam, and blue beech occur sparingly. Brown found in many places as many as 12 distinct species of trees growing on a single quarter acre. (2) The black oak society. On the drier beach and dune ridges, particularly in Sumpter, Romulus, and Taylor townships, the black oak is the dominant species and the woods are more open than those occupied by any other society. These areas were the "oak openings" of pioneer days. Associated with the black oak there are occasionally white oak, wild cherry, sassafras, and wild chestnut. In moist localities the wild chestnut is associated with pin oak, maple, sycamore, and beech. There are four groves of chestnut, two of rather large extent—one east of Dearborn and the other southeast of Belleville. A smaller patch lies north of Wayne, and the fourth is southeast of New Boston and extends into Monroe County.

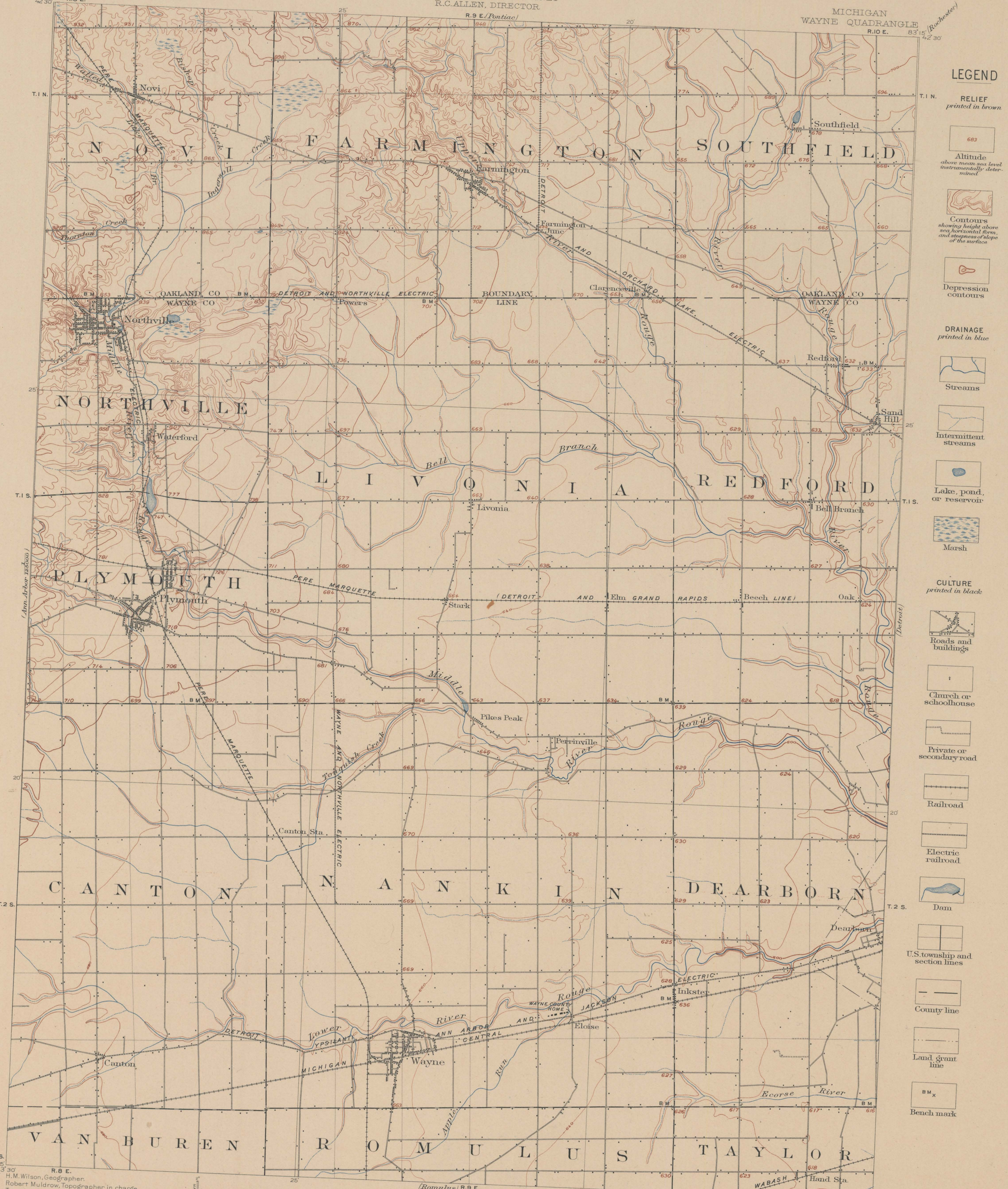
May, 1916.

DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

TOPOGRAPHY

STATE OF MICHIGAN
BOARD OF GEOLOGICAL SURVEY
R.C. ALLEN, DIRECTOR

MICHIGAN
WAYNE QUADRANGLE



H.M. Wilson, Geographer.
Robert Muldrow, Topographer in charge.
Topography by Robert Muldrow and J.T. McCoy.
Control by George T. Hawkins and J.R. Ellis.
Surveyed in 1903.

SURVEYED IN COOPERATION WITH THE STATE OF MICHIGAN.

APPROXIMATE MEAN DECLINATION 1915.

Scale $\frac{1}{62500}$

1 ½ 0 1 2 3 4 Miles

1 ½ 0 1 2 3 4 5 Kilometers

Contour interval 20 feet.
Datum is mean sea level.

DIAGRAM OF TOWNSHIP

6	5	4	3	2	1
7	8	9	10	11	12
18	17	16	15	14	13
19	20	21	22	23	24
30	29	28	27	26	25
31	32	33	34	35	36

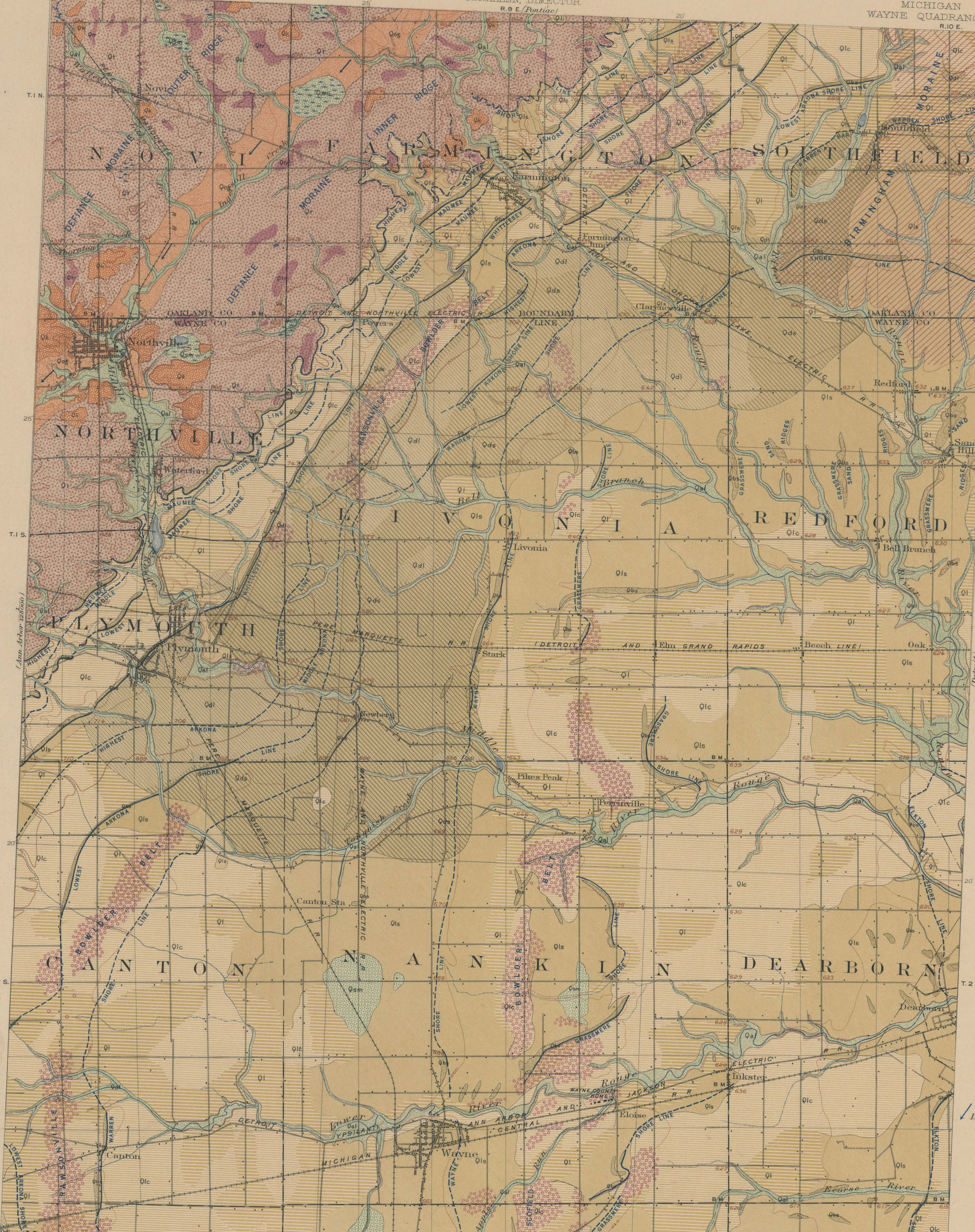
Edition of Feb. 1905, reprinted Sept. 1915.

DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

AREAL GEOLOGY

STATE OF MICHIGAN
BOARD OF GEOLOGICAL SURVEY
R.C. ALLEN, DIRECTOR

MICHIGAN
WAYNE QUADRANGLE



LEGEND

SEDIMENTARY ROCKS

(Areas of subaerial deposits are shown by patterns of dots and circles; subaqueous deposits by patterns of parallel lines)

QUATERNARY

Wisconsin stage of Pleistocene series (includes some Recent)

Recent

- Qsm — Swamp muck and peat
- Qal — Alluvium *(loam, silt, and muck; only larger areas shown)*

(Detroit) — *Deposits in glacial lakes Maumee to Lundy*

- Glacial lake-shore lines *(dashed lines indicate position doubtful or poorly defined)*
- Qbs — Beach sand, pebbly in places *(includes some dune sand)*
- Qls — Lacustrine sand in bed of glacial lakes *(includes some delta, beach, and dune sands)*
- Qds — Pebbly delta sand *(deposited in glacial lakes Maumee to Lundy; includes some beach sand)*
- Qdl — Pebbly delta loam *(deposited in glacial lakes Maumee to Lundy, admixture of pebbly sand and clay)*
- Ql — Lacustrine loamy soil in bed of glacial lakes *(admixture of sand and clay; in part delta deposits; pebbly in places)*
- Qlc — Chiefly lacustrine clay in bed of glacial lakes *(more or less reworked morainal clay; pebbly in places)*

Deposits of Huron-Erie glacial lobe and its associated streams

- Moraine covered by thin lake sediments *(Birmingham moraine deposited in glacial Lake Maumee and its upper portion reworked into lacustrine sand and clay)*
- Bowlder belts *(scattered bowlders and cobbles deposited by glacier along its border)*
- Qog — Outwash gravel *(deposited in channel of glacial stream while Defiance inner ridge was being formed)*
- Qk — Kames *(irregular hills of stratified drift)*
- Qt, Qtr — Morainal till with hilly surface *(Defiance moraine, not submerged by glacial lakes; prominent knolls and ridges indicated by Qtr)*

↙ *Direction of glacial drainage*

Note: *Distribution of bedrock formations is shown in figure in text.*

Clay pits
A *indicates abandoned pit*

Economic note: *Clay for brick and tile can be obtained from* Qal *and* Qt; *gravel for road and concrete from* Qk, Qog, *and portions of* Qbs; *building sand from* Qbs, Qls, *and* Qds; *bowlders and cobbles for construction work from* Qt, Qtr, *and the bowlder belts; peat and moss from* Qsm. *Marl is obtained from some drained swamps.*

H.M. Wilson, Geographer.
Robert Muldrow, Topographer in charge.
Topography by Robert Muldrow and J.T. McCoy.
Control by George T. Hawkins and J.R. Ellis.
Surveyed in 1903.

SURVEYED IN COOPERATION WITH THE STATE OF MICHIGAN.

(Ann Arbor) $\frac{1}{125000}$

TRUE NORTH
MAGNETIC NORTH
2°
APPROXIMATE MEAN DECLINATION 1915.

Scale $\frac{1}{62500}$

1 ½ 0 1 2 3 4 Miles

1 ½ 0 1 2 3 4 5 Kilometers

Contour interval 20 feet.
Datum is mean sea level.
Edition of Jan. 1916.

DIAGRAM OF TOWNSHIP

6	5	4	3	2	1
7	8	9	10	11	12
18	17	16	15	14	13
19	20	21	22	23	24
30	29	28	27	26	25
31	32	33	34	35	36

Geology by W.H. Sherzer.
Surveyed in 1911.

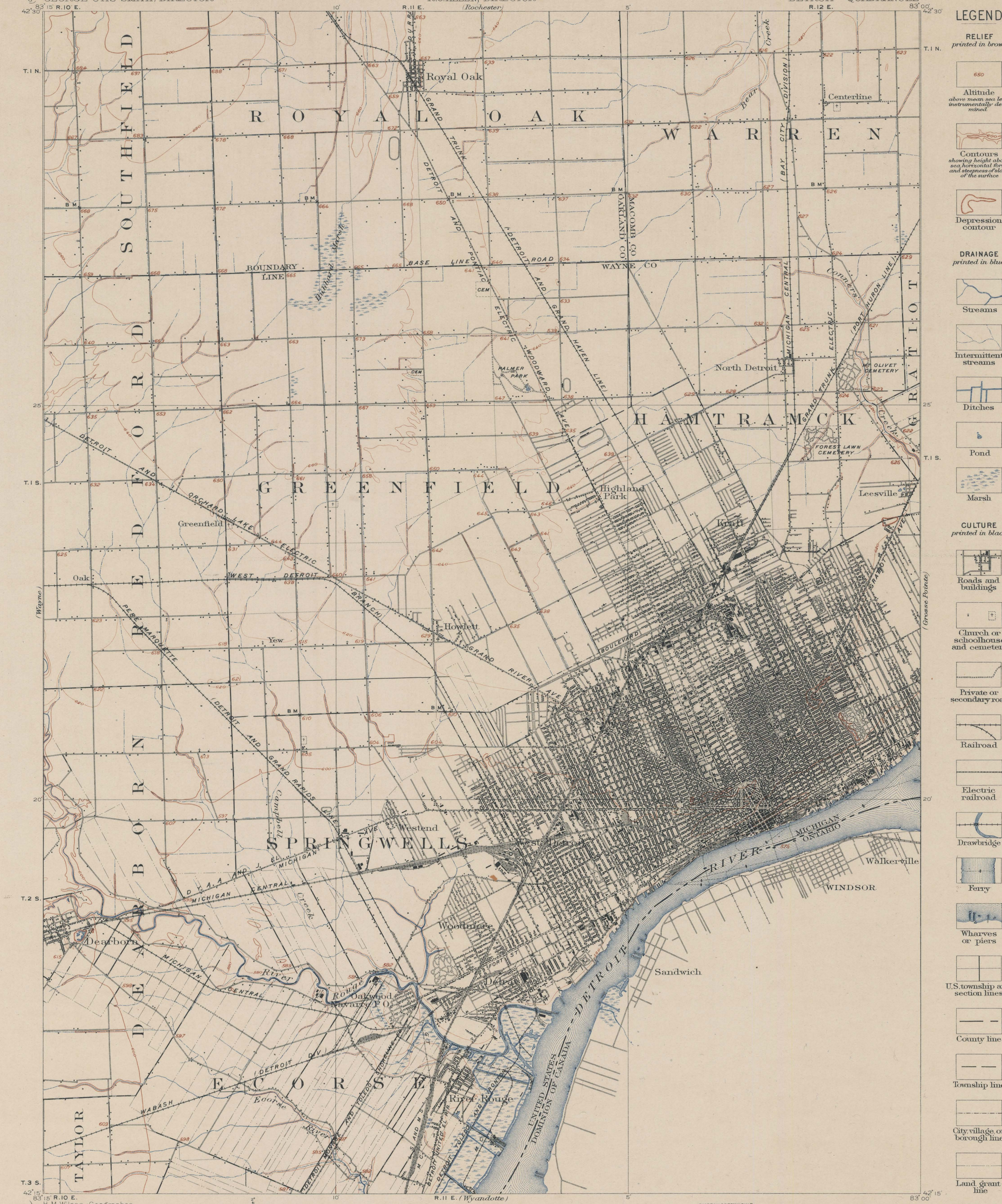
SURVEYED IN COOPERATION WITH THE STATE OF MICHIGAN.

TOPOGRAPHY

DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

STATE OF MICHIGAN
BOARD OF GEOLOGICAL SURVEY
R.C. ALLEN, DIRECTOR

MICHIGAN
DETROIT QUADRANGLE



H.M. Wilson, Geographer.
Chas. E. Cooke, in charge of section.
Topography by Chas. E. Cooke and R.W. Berry.
Assistant, J.N. Williamson.
Control by U.S. Lake Survey, Geo. T. Hawkins, and J.R. Ellis.
Surveyed in 1904.

SURVEYED IN COOPERATION WITH THE STATE OF MICHIGAN.

APPROXIMATE MEAN DECLINATION 1915.

Scale $\frac{1}{62500}$

Contour interval 20 feet.
Datum is mean sea level.

DIAGRAM OF TOWNSHIP

6	5	4	3	2	1
7	8	9	10	11	12
18	17	16	15	14	13
19	20	21	22	23	24
30	29	28	27	26	25
31	32	33	34	35	36

Edition of Dec. 1905, reprinted Sept. 1915.

AREAL GEOLOGY

DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

STATE OF MICHIGAN
BOARD OF GEOLOGICAL SURVEY
R.C. ALLEN, DIRECTOR

MICHIGAN
DETROIT QUADRANGLE

LEGEND

SEDIMENTARY ROCKS

(Areas of subaerial deposits are shown by patterns of dots and circles; subaqueous deposits by patterns of parallel lines)

QUATERNARY

Recent

- **Qsm** — Swamp muck and peat
- **Qal** — Alluvium *(loam, silt, and muck; includes some marsh land; only larger areas shown)*

Wisconsin stage of Pleistocene series (includes some Recent)

Deposits in glacial lakes Maumee to St. Clair

- Glacial lake-shore lines *(dashed lines indicate position doubtful or poorly defined)*
- **Qbs** — Beach sand, pebbly in places *(includes some dune sand)*
- **Qls** — Lacustrine sand in bed of glacial lakes *(includes some beach and dune sands; pebbly in places)*
- **Ql** — Lacustrine loamy soil in bed of glacial lakes *(admixture of sand and clay; pebbly in places)*
- **Qlc** — Chiefly lacustrine clay in bed of glacial lakes *(more or less reworked morainal clay; pebbly in places)*

Deposits of Huron-Erie glacial lobe

- **Qmc** — Moraine largely covered by thin lake sediments *(Detroit interlobate moraine formed beneath the ice, and Mount Clemens and Emmet moraines deposited in glacial Lake Maumee; their upper portions reworked into lacustrine sand and clay; minor ridges of exposed morainal clay of Emmet moraine, Qmc)*

Note: *Distribution of bedrock formations is shown in figure in text.*

- *Clay pits* — A *indicates abandoned pit*
- SALT — *Deep wells from which brine is pumped from rock-salt beds; only principal wells located*
- SALT — *Shaft to rock-salt beds*
- G — *Gas wells*

Economic note: *Brine for salt, soda-ash, and alkali manufacture is obtained from rock-salt beds by deep wells; rock salt for cattle, preserving fish and meat, and refrigeration purposes is obtained by deep shaft. Clay for brick, tile, and coarse pottery is obtained from Qlc; building and brick sand from Qls and Qbs; gravel for roads and concrete from Qbs; peat and moss from Qsm.*

H.M. Wilson, Geographer.
Chas. E. Cooke, in charge of section.
Topography by Chas. E. Cooke and R.W. Berry.
Assistant, J.N. Williamson.
Control by U.S. Lake Survey, Geo. T. Hawkins, and J.R. Ellis.
Surveyed in 1904.

SURVEYED IN COOPERATION WITH THE STATE OF MICHIGAN.

TRUE NORTH
MAGNETIC NORTH
APPROXIMATE MEAN DECLINATION 1904.

Scale $\frac{1}{62500}$

1 ½ 0 1 2 3 4 Miles

1 ½ 0 1 2 3 4 5 Kilometers

Contour interval 20 feet.
Datum is mean sea level.

Edition of Jan. 1916.

DIAGRAM OF TOWNSHIP

6	5	4	3	2	1
7	8	9	10	11	12
18	17	16	15	14	13
19	20	21	22	23	24
30	29	28	27	26	25
31	32	33	34	35	36

Geology by W.H. Sherzer.
Surveyed in 1911.

SURVEYED IN COOPERATION WITH THE STATE OF MICHIGAN.

TOPOGRAPHY

DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

STATE OF MICHIGAN
BOARD OF GEOLOGICAL SURVEY
R.C. ALLEN, DIRECTOR

MICHIGAN
GROSSE POINTE QUADRANGLE

(Wyandotte)

H.M. Wilson, Geographer.
Chas. E. Cooke, in charge of section.
Topography by Chas. E. Cooke and R.W. Berry.
Assistant, J.N. Williamson.
Control by U.S. Lake Survey and J.R. Ellis.
Surveyed in 1904.

SURVEYED IN COOPERATION WITH THE STATE OF MICHIGAN.

APPROXIMATE MEAN DECLINATION 1915.

Scale $\frac{1}{62500}$

Contour interval 20 feet.
Datum is mean sea level.

DIAGRAM OF TOWNSHIP.

6	5	4	3	2	1
7	8	9	10	11	12
18	17	16	15	14	13
19	20	21	22	23	24
30	29	28	27	26	25
31	32	33	34	35	36

Edition of Oct. 1905, reprinted Sept. 1915.

DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

AREAL GEOLOGY

STATE OF MICHIGAN
BOARD OF GEOLOGICAL SURVEY
R.C. ALLEN, DIRECTOR

MICHIGAN
GROSSE POINTE QUADRANGLE

LEGEND

SEDIMENTARY ROCKS

(Areas of subaerial deposits are shown by patterns of dots and circles; subaqueous deposits by patterns of parallel lines)

QUATERNARY

Recent series

Qal — Alluvium *(loam, silt, and muck, includes some marsh land; only larger areas shown)*

Wisconsin stage of Pleistocene series (includes some Recent)

Deposits in glacial lakes Lundy and St. Clair

Glacial lake-shore lines *(dashed lines indicate position doubtful or poorly defined)*

Qbs — Beach sand, pebbly in places *(includes some dune sand)*

Qls — Lacustrine sand in bed of glacial lakes *(includes some beach and dune sands)*

Ql — Lacustrine loamy soil in bed of glacial lakes *(admixture of sand and clay)*

Qlc — Chiefly lacustrine clay in bed of glacial lakes *(more or less reworked morainal clay, pebbly in places)*

Deposits of Huron-Erie glacial lobe

Qmc — Moraine largely covered by thin lake sediments *(Detroit interlobate moraine, and Mount Clemens and Emmet moraines deposited in glacial Lake Maumee; their upper portions reworked into lacustrine sand and clay; minor ridges of exposed morainal clay of Emmet moraine, Qmc)*

Note: *Distribution of bedrock formations is shown in figure in text.*

Economic note: *Clay for brick and tile manufacture can be obtained from* Qlc; *building sand for building and sand-lime brick from* Qbs *and* Qls.

⊙ *Gas wells*

H.M. Wilson, Geographer.
Chas. E. Cooke, in charge of section.
Topography by Chas. E. Cooke and R.W. Berry.
Assistant, J.N. Williamson.
Control by U.S. Lake Survey and J.R. Ellis.
Surveyed in 1904.

SURVEYED IN COOPERATION WITH THE STATE OF MICHIGAN.

TRUE NORTH
MAGNETIC NORTH
APPROXIMATE MEAN DECLINATION 1904.

Scale $\frac{1}{62500}$

1 ½ 0 1 2 3 4 Miles

1 ½ 0 1 2 3 4 5 Kilometers

Contour interval 20 feet.
Datum is mean sea level.

Edition of Jan. 1916.

DIAGRAM OF TOWNSHIP.

6	5	4	3	2	1
7	8	9	10	11	12
18	17	16	15	14	13
19	20	21	22	23	24
30	29	28	27	26	25
31	32	33	34	35	36

Geology by W.H. Sherzer.
Surveyed in 1911.

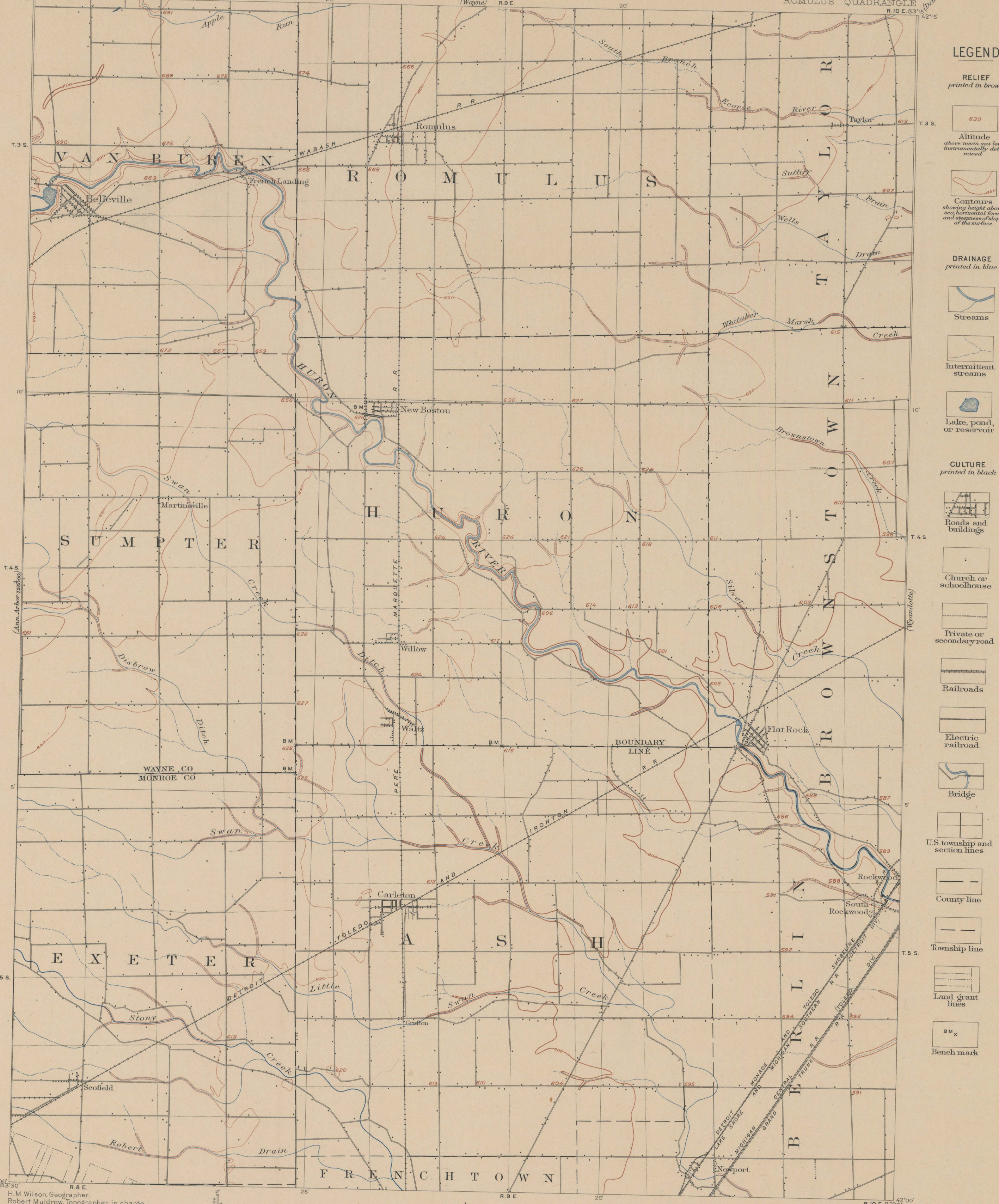
SURVEYED IN COOPERATION WITH THE STATE OF MICHIGAN.

TOPOGRAPHY

DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

STATE OF MICHIGAN
BOARD OF GEOLOGICAL SURVEY
R.C. ALLEN, DIRECTOR

MICHIGAN
ROMULUS QUADRANGLE



H.M. Wilson, Geographer.
Robert Muldrow, Topographer in charge.
Topography by J.T. McCoy.
Triangulation by U.S. Lake Survey.
Surveyed in 1903.

SURVEYED IN COOPERATION WITH THE STATE OF MICHIGAN.

TRUE NORTH
MAGNETIC NORTH
APPROXIMATE MEAN DECLINATION 1915.

Scale $\frac{1}{62500}$

1 ½ 0 1 2 3 4 Miles

1 ½ 0 1 2 3 4 5 Kilometers

Contour interval 20 feet.

Datum is mean sea level.

DIAGRAM OF TOWNSHIP

6	5	4	3	2	1
7	8	9	10	11	12
18	17	16	15	14	13
19	20	21	22	23	24
30	29	28	27	26	25
31	32	33	34	35	36

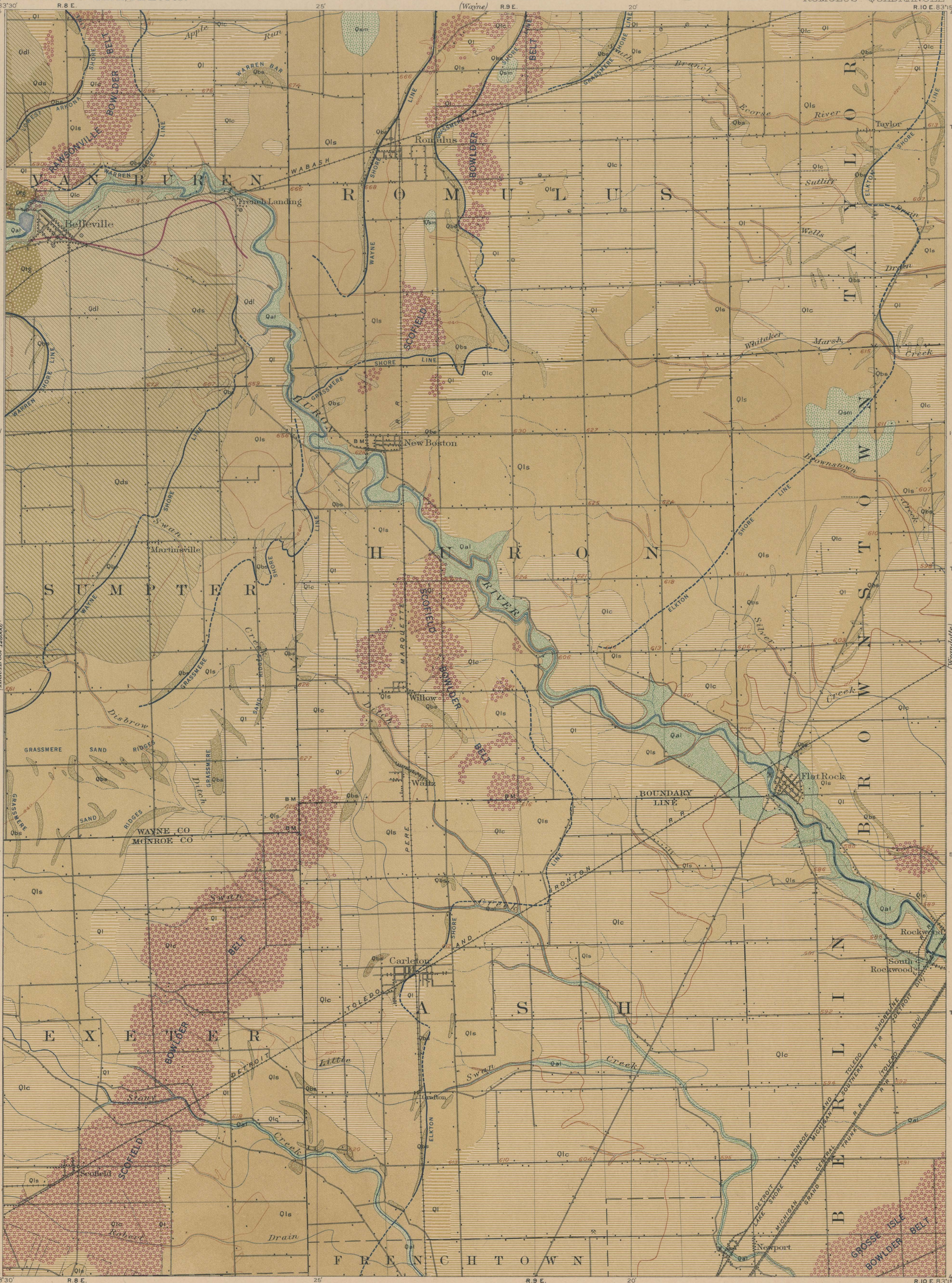
Edition of April 1906, reprinted Sept. 1915.

DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

AREAL GEOLOGY

STATE OF MICHIGAN
BOARD OF GEOLOGICAL SURVEY
R.C. ALLEN, DIRECTOR

MICHIGAN
ROMULUS QUADRANGLE



LEGEND

SEDIMENTARY ROCKS

(Areas of subaerial deposits are shown by patterns of dots and circles; subaqueous deposits by patterns of parallel lines)

QUATERNARY

Recent series

- Qsm — Swamp muck and peat
- Qal — Alluvium *(loam, silt, and muck; only larger areas shown)*

Wisconsin stage of Pleistocene series

Deposits in glacial lakes Maumee to Lundy

- Qtg — Terraced stream gravel *(deposited by glacial Huron River where it entered Lake Warren)*
- Bank of glacial Huron River cut at the time of Lake Wayne
- Glacial lake-shore lines *(dashed lines indicate position doubtful or poorly defined)*
- Qbs — Beach sand, pebbly in places *(includes some dune sand)*
- Qls — Lacustrine sand in bed of glacial lakes *(includes some beach and dune sands)*
- Qds — Pebbly delta sand *(deposited in Lake Arkona; includes some beach sand)*
- Qdl — Pebbly delta loam *(admixture of pebbly delta sand and clay, deposited in Lake Arkona)*
- Ql — Lacustrine loamy soil in bed of glacial lakes *(admixture of sand and clay)*
- Qlc — Lacustrine clay in bed of glacial lakes *(more or less reworked morainal clay)*

Deposits of Huron-Erie glacial lobe

- Bowlder belts *(scattered bowlders and cobbles deposited by glacier along its border)*

Note: *Distribution of bedrock formations is shown in figure in text.*

Economic note: *Clay for brick and tile can be obtained from* Qal *and* Qlc; *building sand from* Qbs, Qls, *and* Qds; *gravel for roads and concrete from* Qdl, Qtg, *and* Qbs; *bowlders and cobbles for construction work from bowlder belts; peat from* Qsm. *Marl and red and yellow ochre are obtained from some drained swamps.*

⊙ *Gas wells*

⚒ *Quarries in bedrock small or abandoned*

✖ *Rock outcrops*

H. M. Wilson, Geographer.
Robert Muldrow, Topographer in charge.
Topography by J. T. McCoy.
Triangulation by U.S. Lake Survey.
Surveyed in 1903.
SURVEYED IN COOPERATION WITH THE STATE OF MICHIGAN.

TRUE NORTH / MAGNETIC NORTH
APPROXIMATE MEAN DECLINATION 1903.

Scale $\frac{1}{62500}$

1 ½ 0 1 2 3 4 Miles

1 ½ 0 1 2 3 4 5 Kilometers

Contour interval 20 feet.
Datum is mean sea level.
Edition of Jan. 1916.

DIAGRAM OF TOWNSHIP

6	5	4	3	2	1
7	8	9	10	11	12
18	17	16	15	14	13
19	20	21	22	23	24
30	29	28	27	26	25
31	32	33	34	35	36

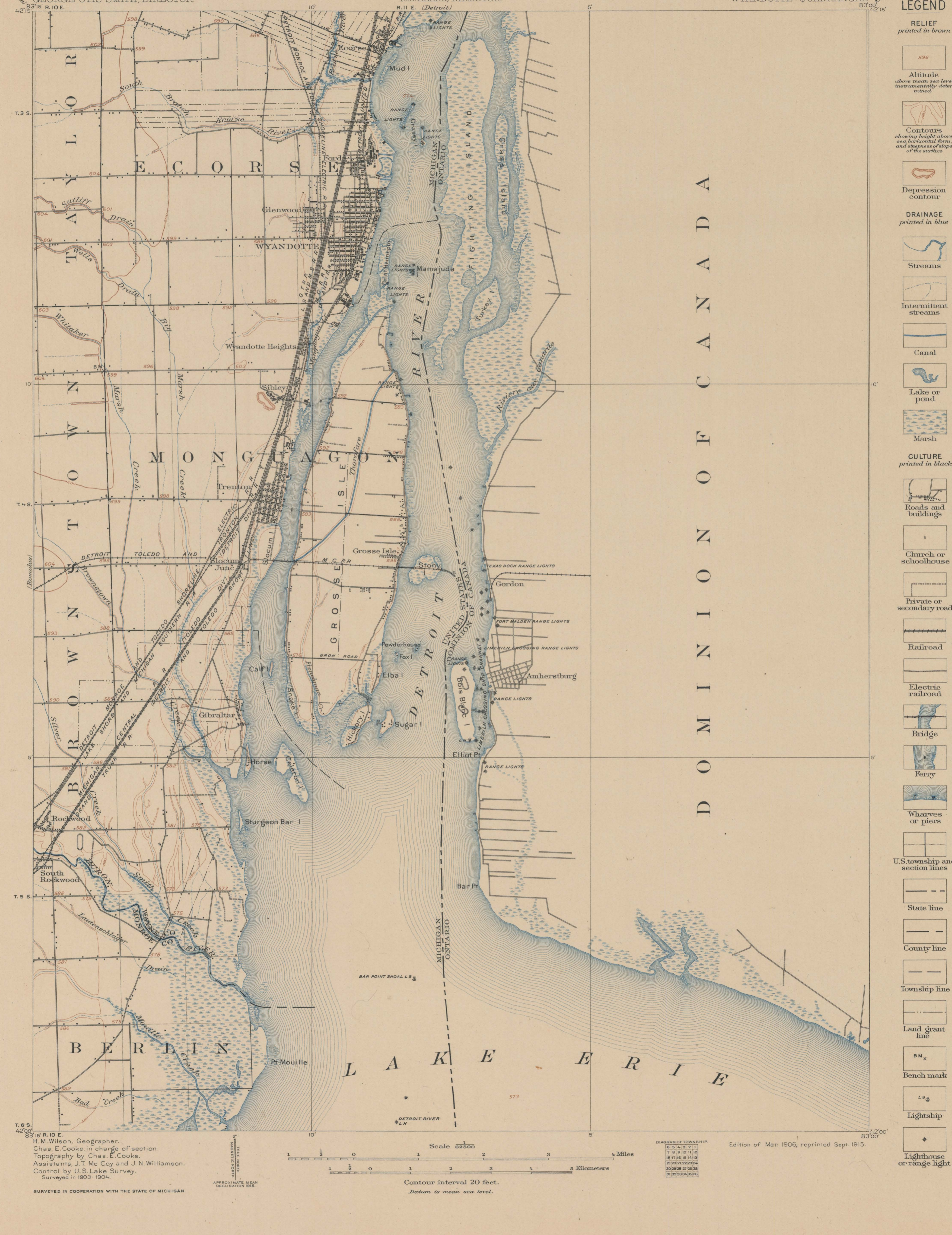
Geology by W. H. Sherzer.
Surveyed in 1911.
SURVEYED IN COOPERATION WITH THE STATE OF MICHIGAN.

TOPOGRAPHY

DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

STATE OF MICHIGAN
BOARD OF GEOLOGICAL SURVEY
R.C. ALLEN, DIRECTOR

MICHIGAN
WYANDOTTE QUADRANGLE



H.M. Wilson, Geographer.
Chas. E. Cooke, in charge of section.
Topography by Chas. E. Cooke.
Assistants, J.T. Mc Coy and J.N. Williamson.
Control by U.S. Lake Survey.
Surveyed in 1903-1904.

SURVEYED IN COOPERATION WITH THE STATE OF MICHIGAN.

TRUE NORTH / MAGNETIC NORTH
APPROXIMATE MEAN DECLINATION 1915.

Scale $\frac{1}{62500}$

1 ½ 0 1 2 3 4 Miles

1 ½ 0 1 2 3 4 5 Kilometers

Contour interval 20 feet.

Datum is mean sea level.

DIAGRAM OF TOWNSHIP

6	5	4	3	2	1
7	8	9	10	11	12
18	17	16	15	14	13
19	20	21	22	23	24
30	29	28	27	26	25
31	32	33	34	35	36

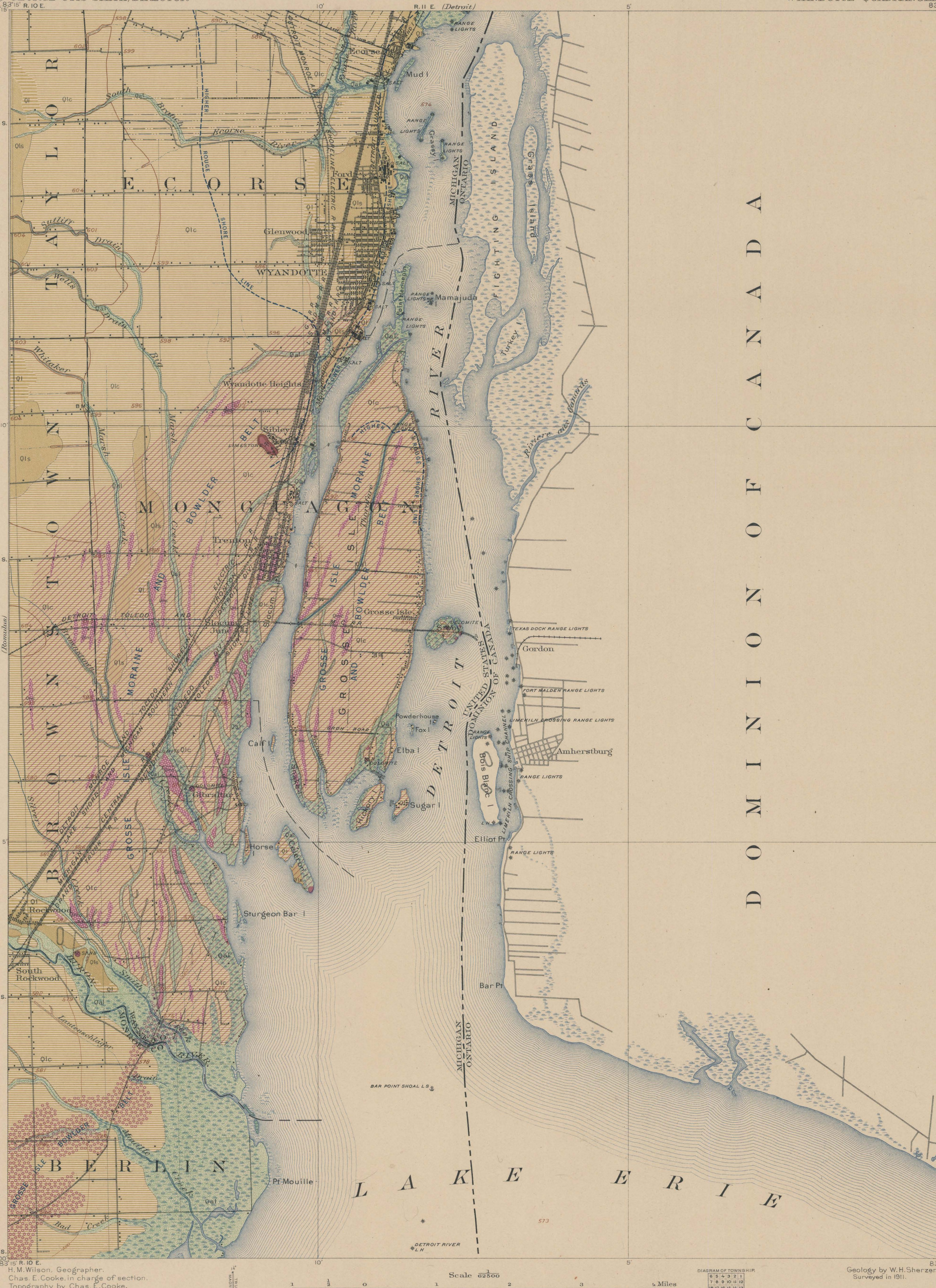
Edition of Mar. 1906, reprinted Sept. 1915.

AREAL GEOLOGY

DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

STATE OF MICHIGAN
BOARD OF GEOLOGICAL SURVEY
R.C. ALLEN, DIRECTOR

MICHIGAN
WYANDOTTE QUADRANGLE



LEGEND

SEDIMENTARY ROCKS

(Areas of subaerial deposits are shown by patterns of dots and circles; subaqueous deposits by patterns of parallel lines)

QUATERNARY

Recent series

Qal — Alluvium *(loam, silt, and muck, in part filling channels of Detroit River distributaries; includes much marsh land; only larger areas shown)*

Wisconsin stage of Pleistocene series (includes some Recent)

Deposits in glacial lakes Lundy and Rouge

Glacial lake-shore lines *(dashed lines indicate position doubtful or poorly defined)*

Qls — Lacustrine sand in bed of glacial lakes *(includes some beach and dune sands)*

Ql — Lacustrine loamy soil in bed of glacial lakes *(admixture of sand and clay)*

Qlc — Chiefly lacustrine clay in bed of glacial lakes *(more-or-less reworked morainal clay)*

Deposits of Huron-Erie glacial lobe

Qmc — Moraine largely covered by thin lake sediments *(Grosse Isle moraine deposited in glacial Lake Maumee, and its upper portion reworked into lacustrine sand and clay; minor ridges of exposed morainal clay, Qmc)*

Bowlder belts *(scattered bowlders and cobbles deposited by glacier along its border; also cover much of morainal area)*

SILURIAN AND DEVONIAN

Bedrock *(small areas of Dundee limestone, Detroit River dolomite, and Sylvania sandstone, exposed chiefly in quarries; distribution of the bedrock formations shown in figure in the text)*

Quarries
Limestone, dolomite, and sand
A, *indicates abandoned quarry*

SALT *Deep wells from which brine is pumped from rock-salt beds; only principal wells located.*

Economic note: *Limestone and dolomite for construction work and road material, and limestone for lime, sand-lime brick, cement, soda-ash, alkali, and beet-sugar manufacture are obtained from quarries in bedrock. Sand for glass manufacture, sanding surfaces, and scouring purposes is quarried from Sylvania sandstone. Brine for manufacture of salt, soda-ash, and alkali is obtained from rock-salt beds by deep wells. Rock salt for cattle, preserving fish and meats, and refrigeration purposes, can be obtained by deep shaft. Clay for brick and tile manufacture can be obtained from* Qlc; *sand for building and sand-lime brick from* Qls.

Glacial striæ
Solid line, latest ice movement; dashed lines, earlier ice movements.

H. M. Wilson, Geographer.
Chas. E. Cooke, in charge of section.
Topography by Chas. E. Cooke.
Assistants, J. T. Mc Coy and J. N. Williamson.
Control by U.S. Lake Survey.
Surveyed in 1903-1904.

SURVEYED IN COOPERATION WITH THE STATE OF MICHIGAN.

TRUE NORTH
MAGNETIC NORTH
APPROXIMATE MEAN DECLINATION 1904.

Scale $\frac{1}{62500}$

1 ½ 0 1 2 3 4 Miles

1 ½ 0 1 2 3 4 5 Kilometers

Contour interval 20 feet.
Datum is mean sea level.

Edition of Jan. 1916.

DIAGRAM OF TOWNSHIP

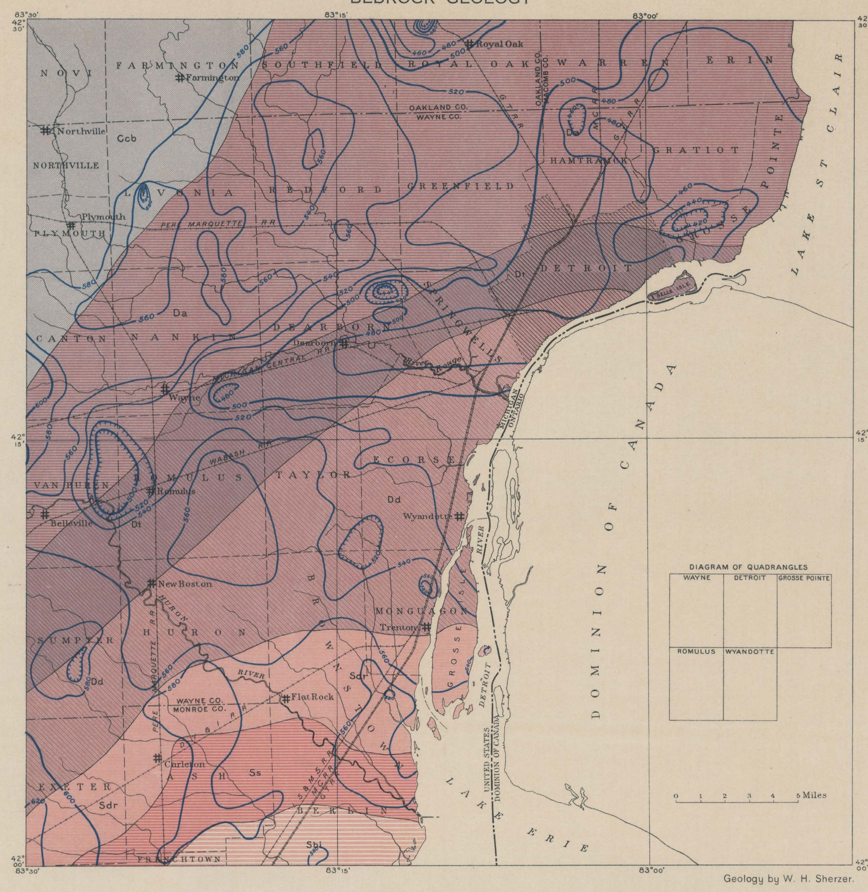
6	5	4	3	2	1
7	8	9	10	11	12
18	17	16	15	14	13
19	20	21	22	23	24
30	29	28	27	26	25
31	32	33	34	35	36

Geology by W. H. Sherzer.
Surveyed in 1911.

SURVEYED IN COOPERATION WITH THE STATE OF MICHIGAN.

SPECIAL MAPS

BEDROCK GEOLOGY



Geology by W. H. Sherzer.

LEGEND

Approximate outcrop of bedrock formations beneath the surficial deposits

CARBONIFEROUS — *Mississippian series*

- **Ccb** — Coldwater shale and underlying Berea sandstone (*light-colored shales, black near base, and coarse gray sandstone at base*)

DEVONIAN — *Upper Devonian*

- **Da** — Antrim shale (*black bituminous shale*)

DEVONIAN — *Middle Devonian*

- **Dt** — Traverse formation (*calcareous shale and thin limestones*)
- **Dd** — Dundee limestone (*bituminous limestone, in part sandy and cherty*)

UNCONFORMITY?

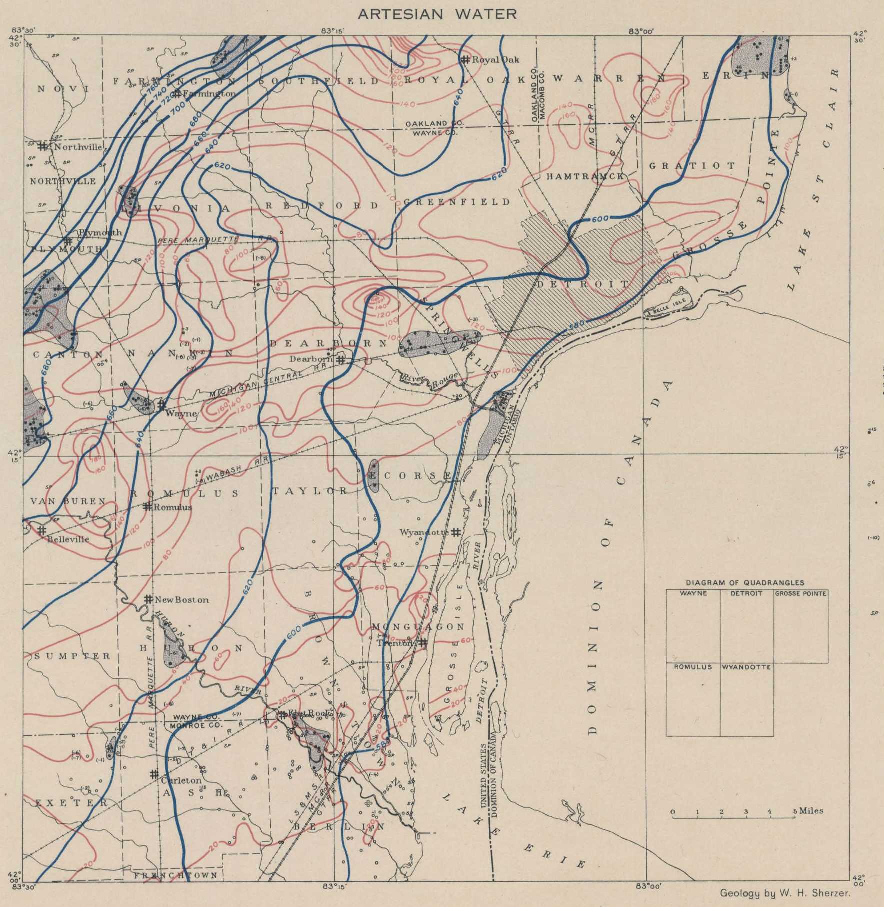
SILURIAN — *Monroe group*

- **Sdr** — Detroit River dolomite (*oolitic, sandy dolomite and thin pure limestone*)
- **Ss** — Sylvania sandstone (*pure white sandstone, crumbling to sand*)
- **Sbi** — Bass Islands dolomite (*dolomite, in part oolitic, and calcareous shale; contains gypsum and salt deposits*)

500 — Approximate altitude of bedrock surface above sea level (*contour interval, 20 feet; fringed lines represent depressions*)

Note: Quarries, gas wells, and other economic data are given on the Areal Geology maps

ARTESIAN WATER



Geology by W. H. Sherzer.

LEGEND

- Area in which flowing wells are known to occur
- 80, 60 — Thickness of surficial deposits which overlie bedrock in area southeast of Defiance moraine (*interval between lines represents difference of 20 feet in thickness*)
- 700 — Artesian head (*approximate elevation above sea level to which artesian water will rise in wells in area southeast of Defiance moraine. Contour interval represents difference of 20 feet in head*)
- +15 — Flowing wells (*figures show approximate height above the surface to which water will rise*)
- 6 — Pump wells that formerly flowed (*figures show approximate depth below the surface to which water will rise*)
- (-10) — Approximate depth below the surface to which water will rise in regions which formerly yielded flowing wells (*determined from wells that have never flowed*)
- SP — Springs

ILLUSTRATIONS

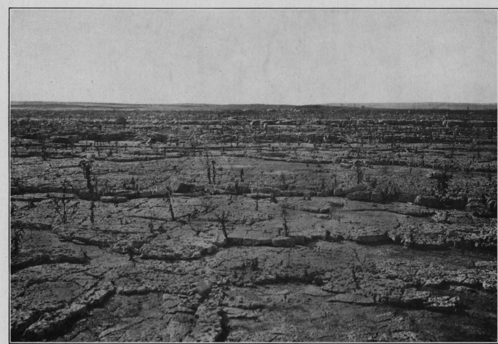


PLATE I.—DETROIT RIVER DOLOMITE TEMPORARILY EXPOSED IN BED OF DETROIT RIVER NEAR STONY ISLAND DURING EXCAVATION OF LIVINGSTONE CHANNEL.

The rock layers are nearly horizontal and their surfaces have been pitted and roughened by solution in the river water. River bed here is free from bowlders.

PLATE II.—DUNDEE LIMESTONE AT SIBLEY QUARRY, STRIPPED OF ITS COVERING OF DRIFT.

The rock surface is smoothed, grooved, and striated by an ice sheet, probably the Illinoian. The grooves and furrows, in one of which the boy sits, strike southwestward. The striae in the foreground strike northwestward. View northwestward.

PLATE III.—DETROIT RIVER DOLOMITE TEMPORARILY EXPOSED IN BED OF DETROIT RIVER NEAR STONY ISLAND DURING EXCAVATION OF LIVINGSTONE CHANNEL.

Shows rock surface smoothed and grooved by the Illinoian ice sheet. Grooves in the rock surface are shown by dark streaks of soil and gravel in the foreground. Illinoian till covers rock surface in face of cut, beneath the dump.

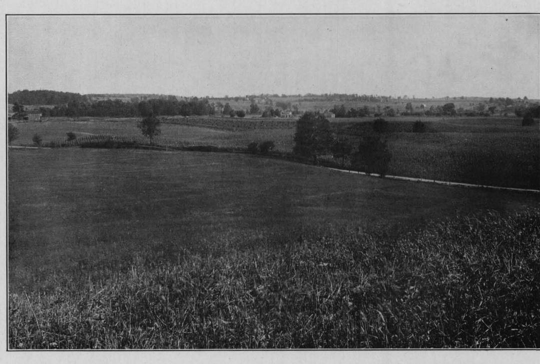


PLATE IV.—VALLEY OF GLACIAL STREAM BETWEEN OUTER AND INNER RIDGES OF DEFIANCE MORAINE.

View eastward from crest of the outer ridge toward inner ridge in distance.

PLATE V.—SECTION OF ILLINOIAN TILL TEMPORARILY EXPOSED IN BED OF DETROIT RIVER NEAR STONY ISLAND DURING EXCAVATION OF LIVINGSTONE CHANNEL.

This till is very stony compared with the Wisconsin till, shown in Plate VI.

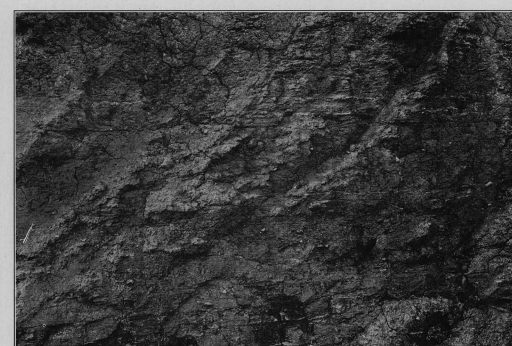


PLATE VI.—WISCONSIN TILL, HORIZONTALLY LAMINATED AND NEARLY FREE FROM PEBBLES EXPOSED IN STRIPPING AT SIBLEY QUARRY.

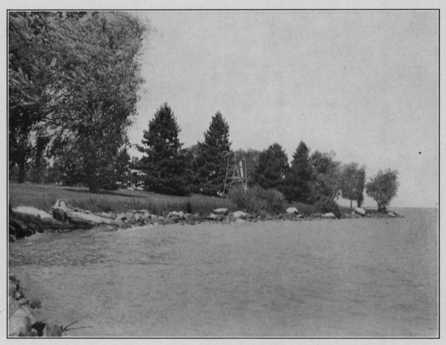


PLATE VII.—MILK RIVER POINT, LAKE ST. CLAIR, FORMED BY BOWLDERS, WHICH HAVE PROTECTED IT FROM EROSION.

Bowlders along the shore have been washed out of the Emmet Moraine.

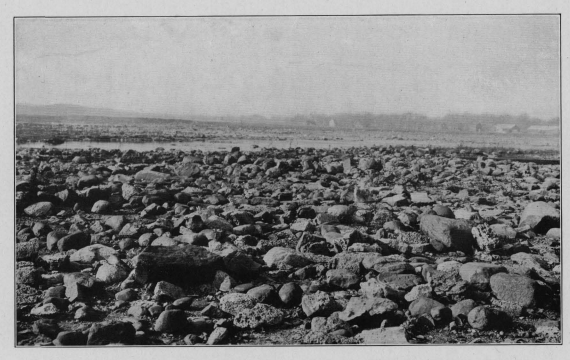


PLATE VIII.—BOWLDERS OF GROSSE ISLE MORAINE COVERING BED OF DETROIT RIVER NEAR STONY ISLAND, TEMPORARILY BARED DURING EXCAVATION OF LIVINGSTONE CHANNEL.

PLATE IX.—KAME GRAVEL COVERED BY LATER TILL DEPOSITED DURING READVANCE OF THE ICE 1 MILE NORTHWEST OF FARMINGTON.

The till is the harder material at the top, overlying the kame gravel in the pit.

PLATE X.—SECTION OF KAME DEPOSIT JUST EAST OF NORTHVILLE.

Gravel of the kame is used as road material. Rejected cobble and larger bowlders from the gravel are piled at base of cut.

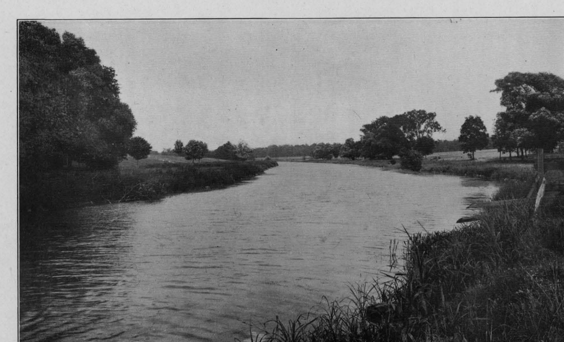


PLATE XI.—THE THOROUGHFARE, ON GROSSE ISLE.

A distributary channel of glacial Detroit River between ridges of the Grosse Isle moraine.

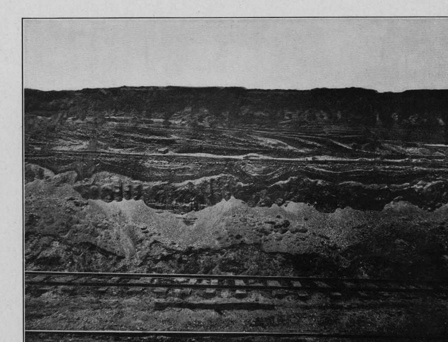


PLATE XII.—SECTION OF THE BEACH DEPOSIT OF GLACIAL LAKE WHITTLESEY 1 MILE NORTHEAST OF PLYMOUTH.

Shows strongly marked cross-bedding in the sand and gravel of the deposit.

No.*	Name of folio.	State.	Price.†
			Cents.
‡1	Livingston	Montana	
‡2	Ringgold	Georgia-Tennessee	
•3	Placerville	California	
‡4	Kingston	Tennessee	
•5	Sacramento	California	
‡6	Chattanooga	Tennessee	
‡7	Pikes Peak	Colorado	
‡8	Sewanee	Tennessee	
‡9	Anthracite-Crested Butte	Colorado	
‡10	Harpers Ferry	Va.-Md.-W.Va	
•11	Jackson	California	
‡12	Estillville	Ky.-Va.-Tenn	
‡13	Fredericksburg	Virginia-Maryland	
‡14	Staunton	Virginia-West Virginia	
‡15	Lassen Peak	California	
‡16	Knoxville	Tennessee-North Carolina	
‡17	Marysville	California	
‡18	Smartsville	California	
‡19	Stevenson	Ala.-Ga.-Tenn	
20	Cleveland	Tennessee	5
‡21	Pikeville	Tennessee	
‡22	McMinnville	Tennessee	
23	Nomini	Maryland-Virginia	5
‡24	Three Forks	Montana	
‡25	Loudon	Tennessee	
‡26	Pocahontas	Virginia-West Virginia	
‡27	Morristown	Tennessee	
‡28	Piedmont	West Virginia-Maryland	
‡29	Nevada City Special	California	
‡30	Yellowstone National Park	Wyoming	
‡31	Pyramid Peak	California	
‡32	Franklin	West Virginia-Virginia	
‡33	Briceville	Tennessee	
‡34	Buckhannon	West Virginia	
‡35	Gadsden	Alabama	
36	Pueblo	Colorado	5
‡37	Downieville	California	
‡38	Butte Special	Montana	
‡39	Truckee	California	
‡40	Wartburg	Tennessee	
‡41	Sonora	California	
42	Nueces	Texas	5
‡43	Bidwell Bar	California	
‡44	Tazewell	Virginia-West Virginia	
‡45	Boise	Idaho	
‡46	Richmond	Kentucky	
‡47	London	Kentucky	
‡48	Tenmile District Special	Colorado	
‡49	Roseburg	Oregon	
‡50	Holyoke	Massachusetts-Connecticut	
‡51	Big Trees	California	
‡52	Absaroka	Wyoming	
‡53	Standingstone	Tennessee	
‡54	Tacoma	Washington	
‡55	Fort Benton	Montana	
‡56	Little Belt Mountains	Montana	
‡57	Telluride	Colorado	
‡58	Elmoro	Colorado	
‡59	Bristol	Virginia-Tennessee	
‡60	La Plata	Colorado	
‡61	Monterey	Virginia-West Virginia	
62	Menominee Special	Michigan	5
‡63	Mother Lode District	California	
‡64	Uvalde	Texas	
65	Tintic Special	Utah	5
‡66	Colfax	California	
67	Danville	Illinois-Indiana	5
68	Walsenburg	Colorado	5
‡69	Huntington	West Virginia-Ohio	
‡70	Washington	D. C.-Va.-Md.	
‡71	Spanish Peaks	Colorado	
‡72	Charleston	West Virginia	
‡73	Coos Bay	Oregon	
‡74	Coalgate	Oklahoma (Ind. T.)	
75	Maynardville	Tennessee	5
‡76	Austin	Texas	
‡77	Raleigh	West Virginia	
78	Rome	Georgia-Alabama	5
‡79	Atoka	Oklahoma (Ind. T.)	
‡80	Norfolk	Virginia-North Carolina	
‡81	Chicago	Illinois-Indiana	
‡82	Masontown-Uniontown	Pennsylvania	
‡83	New York City	New York-New Jersey	
84	Ditney	Indiana	5
85	Oelrichs	South Dakota-Nebraska	5
86	Ellensburg	Washington	5
87	Camp Clarke	Nebraska	5
88	Scotts Bluff	Nebraska	5
89	Port Orford	Oregon	5
90	Cranberry	North Carolina-Tennessee	5
91	Hartville	Wyoming	5
92	Gaines	Pennsylvania-New York	5
93	Elkland-Tioga	Pennsylvania	5
‡94	Brownsville-Connellsville	Pennsylvania	
95	Columbia	Tennessee	5
96	Olivet	South Dakota	5
97	Parker	South Dakota	5
98	Tishomingo	Oklahoma (Ind. T.)	5
99	Mitchell	South Dakota	5
100	Alexandria	South Dakota	5
101	San Luis	California	5
102	Indiana	Pennsylvania	5
103	Nampa	Idaho-Oregon	5

No.*	Name of folio.	State.	Price.†
			Cents.
104	Silver City	Idaho	5
105	Patoka	Indiana-Illinois	5
106	Mount Stuart	Washington	5
107	Newcastle	Wyoming-South Dakota	5
108	Edgemont	South Dakota-Nebraska	5
109	Cottonwood Falls	Kansas	5
‡110	Latrobe	Pennsylvania	
‡111	Globe	Arizona	
112	Bisbee (reprint)	Arizona	25
113	Huron	South Dakota	5
114	De Smet	South Dakota	5
‡115	Kittanning	Pennsylvania	
116	Asheville	North Carolina-Tennessee	5
117	Casselton-Fargo	North Dakota-Minnesota	5
118	Greeneville	Tennessee-North Carolina	5
119	Fayetteville	Arkansas-Missouri	5
‡120	Silverton	Colorado	
‡121	Waynesburg	Pennsylvania	
122	Tahlequah	Oklahoma (Ind. T.)	5
123	Elders Ridge	Pennsylvania	5
124	Mount Mitchell	North Carolina-Tennessee	5
‡125	Rural Valley	Pennsylvania	
‡126	Bradshaw Mountains	Arizona	
‡127	Sundance	Wyoming-South Dakota	
‡128	Aladdin	Wyo.-S. Dak.-Mont	
‡129	Clifton	Arizona	
‡130	Rico	Colorado	
‡131	Needle Mountains	Colorado	
‡132	Muscogee	Oklahoma (Ind. T.)	
‡133	Ebensburg	Pennsylvania	
‡134	Beaver	Pennsylvania	
‡135	Nepesta	Colorado	
136	St. Marys	Maryland-Virginia	5
137	Dover	Del.-Md.-N. J	5
‡138	Redding	California	
‡139	Snoqualmie	Washington	
‡140	Milwaukee Special	Wisconsin	
‡141	Bald Mountain-Dayton	Wyoming	
‡142	Cloud Peak-Fort McKinney	Wyoming	
143	Nantahala	North Carolina-Tennessee	5
‡144	Amity	Pennsylvania	
‡145	Lancaster-Mineral Point	Wisconsin-Iowa-Illinois	
146	Rogersville	Pennsylvania	5
147	Pisgah	N. Carolina-S. Carolina	5
148	Joplin District (reprint)	Missouri-Kansas	50
‡149	Penobscot Bay	Maine	
‡150	Devils Tower	Wyoming	
‡151	Roan Mountain	Tennessee-North Carolina	
152	Patuxent	Md.-D. C	5
‡153	Ouray	Colorado	
‡154	Winslow	Ark.-Okla. (Ind. T.)	
155	Ann Arbor (reprint)	Michigan	25
‡156	Elk Point	S. Dak.-Nebr.-Iowa	
‡157	Passaic	New Jersey-New York	
158	Rockland	Maine	5
159	Independence	Kansas	5
160	Accident-Grantsville	Md.-Pa.-W. Va.	5
‡161	Franklin Furnace	New Jersey	
‡162	Philadelphia	Pa.-N. J.-Del	
‡163	Santa Cruz	California	
‖164	Belle Fourche	South Dakota	5
‖165	Aberdeen-Redfield	South Dakota	5
¶166	El Paso	Texas	5
‡167	Trenton	New Jersey-Pennsylvania	
‖168	Jamestown-Tower	North Dakota	5
‡169	Watkins Glen-Catatonk	New York	
‖170	Mercersburg-Chambersburg	Pennsylvania	5
‖171	Engineer Mountain	Colorado	5
‖172	Warren	Pennsylvania-New York	5
‖173	Laramie-Sherman	Wyoming	5
‖174	Johnstown	Pennsylvania	5
¶175	Birmingham	Alabama	5
‖176	Sewickley	Pennsylvania	5
¶177	Burgettstown-Carnegie	Pennsylvania	5
‖178	Foxburg-Clarion	Pennsylvania	5
‖179	Pawpaw-Hancock	Md.-W. Va.-Pa	5
‖180	Claysville	Pennsylvania	5
‖181	Bismarck	North Dakota	5
‖182	Choptank	Maryland	5
‖183	Llano-Burnet	Texas	5
‖184	Kenova	Ky.-W. Va.-Ohio	5
§185	Murphysboro-Herrin	Illinois	25
§186	Apishapa	Colorado	5
§187	Ellijay	Ga.-N. C.-Tenn.	25
§188	Tallula-Springfield	Illinois	25
189	Barnesboro-Patton	Pennsylvania	25
§190	Niagara	New York	50
§191	Raritan	New Jersey	25
192	Eastport	Maine	25
§193	San Francisco	California	75
194	Van Horn	Texas	25
195	Belleville-Breese	Illinois	25
196	Philipsburg	Montana	25
§197	Columbus	Ohio	25
198	Castle Rock	Colorado	25
199	Silver City	New Mexico	25
200	Galena-Elizabeth	Illinois-Iowa	25
§201	Minneapolis-St. Paul	Minnesota	25
202	Eureka Springs-Harrison	Arkansas-Missouri	25
203	Colorado Springs	Colorado	25
204	Tolchester	Maryland	25
§205	Detroit	Michigan	50
206	Leavenworth-Smithville	Missouri-Kansas	25

* Order by number.
† Payment must be made by money order or in cash.
‡ These folios are out of stock.

‖ Octavo editions of these folios may be had at same price.
¶ Octavo editions only of these folios are in stock.
§ These folios are also published in octavo form at 50 cents each, except No. 193,