DEPARTMENT OF THE INTERIOR

UNITED STATES GEOLOGICAL SURVEY

CHARLES D. WALCOTT, DIRECTOR

GEOLOGIC ATLAS

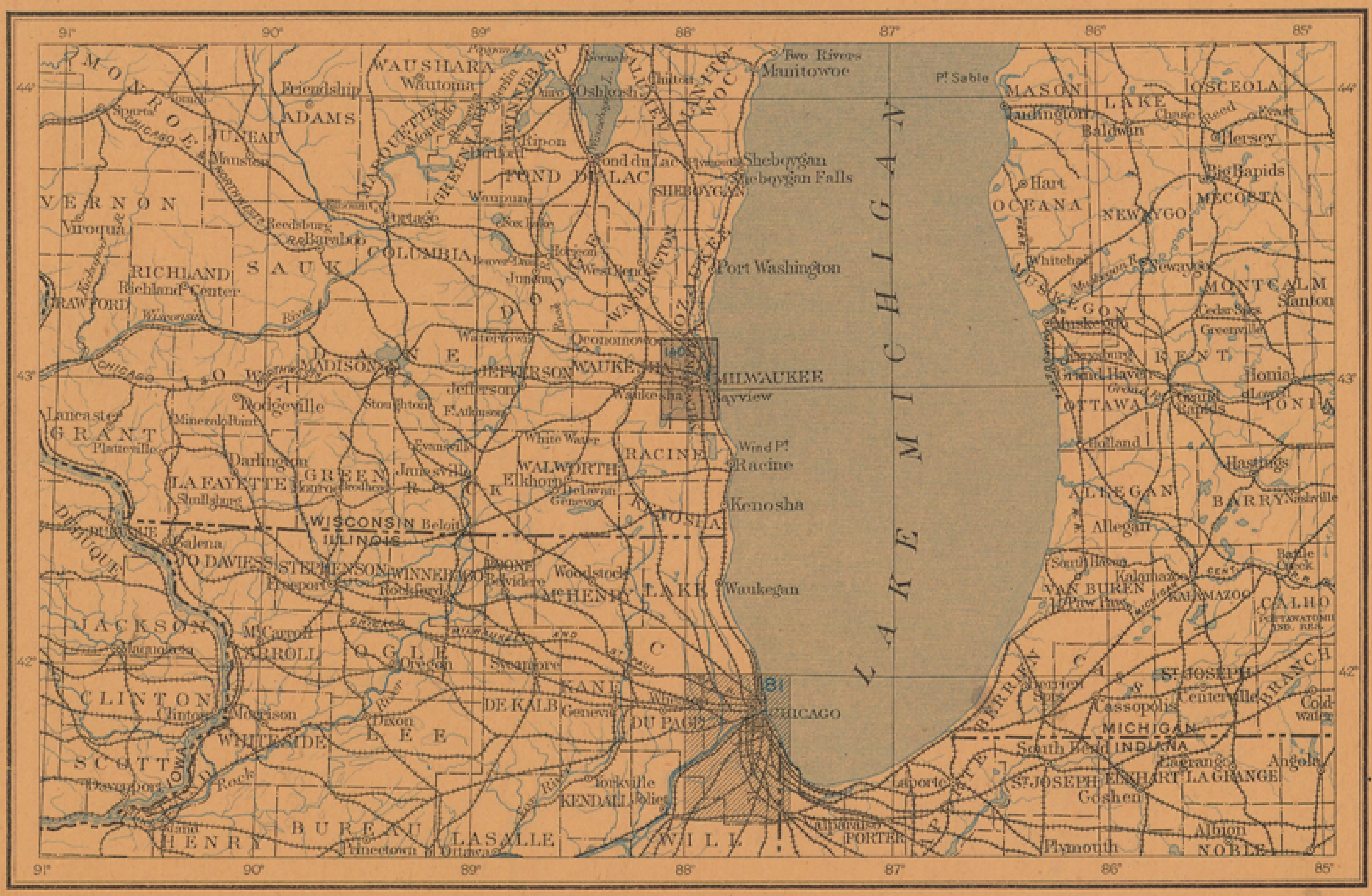
OF THE

UNITED STATES

MILWAUKEE SPECIAL FOLIO

WISCONSIN

INDEX MAP



SCALE: 40 MILES = 1 INCH

MILWAUKEE SPECIAL FOLIO

OTHER PUBLISHED FOLIOS

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GEOLOGIC AND TOPOGRAPHIC ATLAS OF UNITED STATES.

The Geological Survey is making a geologic map of the United States, which is being issued in parts, called folios. Each folio includes a topographic map and geologic maps of a small area of country, together with explanatory and descriptive texts.

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 which are most important 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 altitudinal interval represented by the space between lines being the same throughout each map. These lines are called *contours*, and the uniform altitudinal space between each two contours is called the *contour interval*. Contours and elevations are printed in brown.

The manner in which contours express elevation, form, and grade is shown in the following sketch and corresponding contour map (fig. 1).

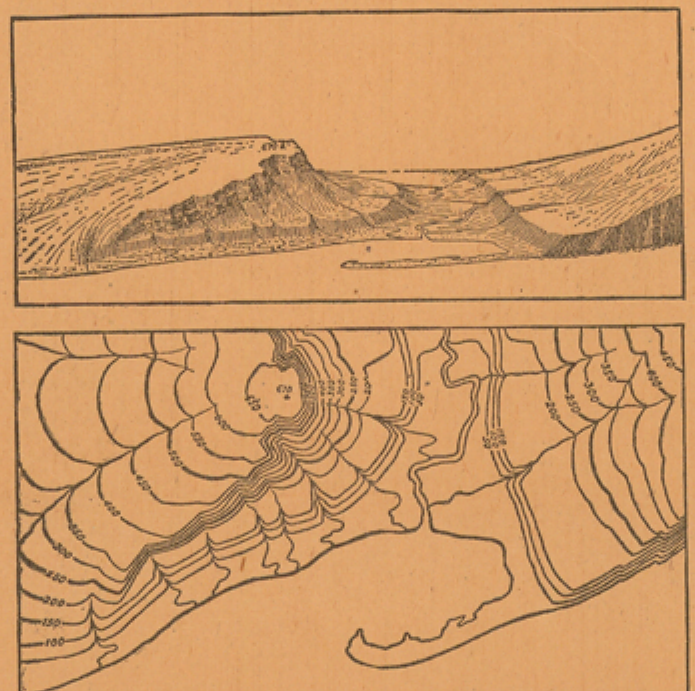


Fig. 1.—Ideal view and corresponding contour map.

The sketch represents a river valley between two hills. In the foreground is the sea, with a bay which is partly closed by a hooked sand bar. On each side of the valley is a terrace. From the terrace on the right a hill rises gradually, while from that on the left the ground ascends steeply, forming a precipice. Contrasted with this precipice is the gentle slope from its top toward the left. In the map each of these features is indicated, directly beneath its position in the sketch, by contours. The following explanation may make clearer the manner in which contours delineate elevation, form, and grade:

1. A contour indicates a certain height above sea level. In this illustration the contour interval is 50 feet; therefore the contours 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 sea; along the contour at 200 feet, all points that are 200 feet above sea; and so on. In the space between any two contours are found elevations above the lower and below the higher contour. Thus the contour at 150 feet falls just below the edge of the terrace, while 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 sea. The summit of the higher hill is stated to be 670 feet above sea; accordingly the contour at 650 feet surrounds it. In this illustration all the contours are numbered, and those for 250 and 500 feet are accentuated by being made heavier. Usually it is not desirable to number all the contours, and then the accentuating and numbering of certain of them—say every fifth one—suffice, for the heights of others may be ascertained by counting up or down from a numbered contour.

2. Contours define the forms of slopes. Since contours are continuous horizontal lines, they wind smoothly about smooth surfaces, recede into all reentrant angles of ravines, and project in passing about prominences. These relations of contour curves and angles to forms of the landscape can be traced in the map and sketch.

3. Contours show the approximate grade of any slope. The altitudinal space between two contours is the same, whether they lie along a cliff or on a gentle slope; but to rise 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.

For a flat or gently undulating country a small contour interval is used; for a steep or mountainous country a large interval is necessary. The smallest interval used on the atlas sheets of the Geological Survey is 5 feet. This is serviceable for regions like the Mississippi delta and the Dismal Swamp. In mapping great mountain masses, like those in Colorado, the interval may be 250 feet. For intermediate relief contour intervals of 10, 20, 25, 50, and 100 feet are used.

Drainage.—Watercourses are indicated by blue lines. If a stream flows the entire year the line is drawn unbroken, but if the channel is dry a part of the year the line is broken or dotted. Where a stream sinks and reappears at the surface, the supposed underground course is shown by a broken blue line. Lakes, marshes, and other bodies of water are also shown in blue, by appropriate conventional signs.

Culture.—The works of man, such as roads, railroads, and towns, together with boundaries of townships, counties, and States, are printed in black.

Scales.—The area of the United States (excluding Alaska and island possessions) is about 3,025,000 square miles. A map representing this area, drawn to the scale of 1 mile to the inch, would cover 3,025,000 square inches of paper, and to accommodate the map the paper would need to measure about 240 by 180 feet. Each square mile of ground surface would be represented by a square inch of map surface, and one linear mile on the ground would be represented by a linear inch on the map. This relation between distance in nature and corresponding distance on the map is called the *scale* of the map. In this case it is "1 mile to an inch." 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 an inch" is expressed by $\frac{1}{63,360}$.

Three scales are used on the atlas sheets of the Geological Survey; the smallest is $\frac{1}{250,000}$, the intermediate $\frac{1}{125,000}$, and the largest $\frac{1}{62,500}$. These correspond approximately to 4 miles, 2 miles, and 1 mile on the ground to an inch on the map. On the scale $\frac{1}{62,500}$ a square inch of map surface represents about 1 square mile of earth surface; on the scale $\frac{1}{125,000}$, about 4 square miles; and on the scale $\frac{1}{250,000}$, 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 in English inches, by a similar line indicating distance in the metric system, and by a fraction.

Atlas sheets and quadrangles.—The map 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 $\frac{1}{250,000}$ contains one square degree—i. e., a degree of latitude by a degree of longitude; each sheet on the scale of $\frac{1}{125,000}$ contains one-fourth of a square degree; each sheet on the scale of $\frac{1}{62,500}$ contains one-sixteenth of a square degree. The areas of the corresponding quadrangles are about 4000, 1000, and 250 square miles.

The atlas sheets, being only parts of one map of the United States, disregard political boundary lines, such as those of States, counties, and townships. 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 the names of adjacent sheets, if published, are printed.

Uses of the topographic map.—On the topographic map are delineated the relief, drainage, and culture of the quadrangle represented. It should portray to the observer every characteristic feature of the landscape. It should guide the traveler; serve the investor or owner who desires to ascertain the position and surroundings of property; save the engineer preliminary surveys in locating roads, railways, and irrigation reservoirs and ditches; provide educational material for schools and homes; and be useful as a map for local reference.

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 the structure sections show their underground relations, as 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.—These are rocks which have cooled and consolidated from a state of fusion. Through rocks of all ages molten material has from time to time been forced upward in fissures or channels of various shapes and sizes, to or nearly to the surface. Rocks formed by the consolidation of the molten mass within these channels—that is, below the surface—are called *intrusive*. When the rock occupies a fissure with approximately parallel walls the mass is called a *dike*; when it fills a large and irregular conduit the mass is termed a *stock*. When the conduits for molten magmas traverse stratified rocks they often send off branches parallel to the bedding planes; the rock masses filling such fissures are called *sills* or *sheets* when comparatively thin, and *laccoliths* when occupying larger chambers produced by the force propelling the magmas upward. Within rock inclosures molten material cools slowly, with the result that intrusive rocks are generally of crystalline texture. When the channels reach the surface the molten material poured out through them is called *lava*, and lavas often build up volcanic mountains. Igneous rocks thus formed upon the surface are called *extrusive*. Lavas cool rapidly in the air, and acquire a glassy or, more often, a partially crystalline condition in their outer parts, but are more fully crystalline in their inner portions. The outer parts of lava flows are usually more or less porous. Explosive action often accompanies volcanic eruptions, causing ejections of dust, ash, and larger fragments. These materials, when consolidated, constitute breccias, agglomerates, and tuffs. Volcanic ejecta may fall in bodies of water or may be carried into lakes or seas and form sedimentary rocks.

Sedimentary rocks.—These rocks are composed of the materials of older rocks which have been broken up and the fragments of which have been carried to a different place and deposited.

The chief agent of 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. In smaller portion the materials are carried in solution, and the deposits are then 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 deposits 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*. Rocks deposited in layers are said to be stratified.

The surface of the earth is not fixed, as it seems to be; it very slowly rises or sinks, with reference to the sea, over wide expanses; and as it rises or subsides the shore lines of the ocean are changed. As a result of the rising of the surface, marine sedimentary rocks may become part of the land, and extensive land areas are in fact occupied by such rocks.

Rocks exposed at the surface of the land are acted upon by air, water, ice, animals, and plants. They are gradually broken into fragments, and the more soluble parts are leached out, leaving the less soluble as a *residual* layer. Water washes residual material down the slopes, and it is eventually carried by rivers to the ocean or other bodies of standing water. Usually its journey is not continuous, but it is temporarily built into river bars and flood plains, where it is called *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 a variety of processes, rocks may become greatly changed in composition and in texture. When the newly acquired characteristics are more pronounced than the old ones such rocks are called *metamorphic*. In the process of metamorphism the substances of which a rock is composed may enter into new combinations, certain substances may be lost, or new substances may be added. There is often a complete gradation from the primary to the metamorphic form within a single rock mass. Such changes transform sandstone into quartzite, limestone into marble, and modify other rocks in various ways.

From time to time in geologic history igneous and sedimentary rocks have been deeply buried and later have been raised to the surface. In this process, through the agencies of pressure, movement, and chemical action, their original structure may be entirely lost and new structures appear. Often there is developed a system of division planes along which the rocks split easily, and these planes may cross the strata at any angle. This structure is called *cleavage*. Sometimes crystals of mica or other foliaceous minerals are developed with their laminæ approximately parallel; in such cases the structure is said to be schistose, or characterized by *schistosity*.

As a rule, the oldest rocks are most altered and the younger formations have escaped metamorphism, but to this rule there are important exceptions.

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, a rapid alternation of shale and limestone. When the passage from one kind of rocks to another is gradual it is sometimes 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 is constituted of one or more bodies either containing the same kind of igneous rock or having the same mode of occurrence. A metamorphic formation may consist of rock of uniform character or of several rocks having common characteristics.

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

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*.

(Continued on third page of cover.)

DESCRIPTION OF THE MILWAUKEE QUADRANGLE.

Prepared under the supervision of T. C. Chamberlin, geologist in charge.

By William C. Alden.

GEOGRAPHY.

Geographic relations.—The area mapped and described in this folio covers the greater part of Milwaukee County and extends about a mile westward into Waukesha County, Wis. It is bounded by parallels 42° 54′ and 43° 09′ north latitude and meridians 87° 05′ and 88° 05′ west longitude, thus comprising one-sixteenth of a square degree of the earth's surface, or about $218\frac{1}{4}$ square miles. Of this area about 181 square miles are land. On the east are the waters of Lake Michigan.

TOPOGRAPHY.

Relief.—The region is, in general, characterized by the moderately undulating drift topography common to the northern Mississippi Valley. Along the lake shore, except near the mouth of Milwaukee River, there is a bluff rising 60 to 120 feet above the lake. From the crest of this bluff the undulating surface rises gradually toward the west, and in the western part of Milwaukee County elevations 220 to 260 feet above Lake Michigan, or 800 to 840 feet above sea level, are attained. This rise continues westward beyond the area here described, reaching 1300 feet above sea level, the maximum elevation for southeastern Wisconsin, at Holy Hill, in the southwestern part of Washington County, 21 miles west of Lake Michigan, and 1240 feet, the next highest elevation, at Government Hill, 2 miles southeast of Delafield, in the western part of Waukesha County, 25 miles west of the lake. The relief of the undulations also becomes somewhat greater toward the west, in Waukesha County.

In Milwaukee County and in the eastern part of Waukesha County these undulations form a series of broad, gentle ridges or swells 1 to 3 miles in width, having a trend nearly parallel to the lake shore. This parallel-ridged topography is rather more markedly developed to the north, in Ozaukee County, and to the south, in Racine and Kenosha counties.

Drainage.—The location of the drainage lines is consequent upon the topography. The work of the streams has been confined almost entirely to the deepening of the channels, while the valley slopes have scarcely been touched by erosion. Many marsh areas are yet undrained, the gradients of the streams are still high, and the lower courses, where most of the erosion has taken place, are in general sharply V-shaped, with valley bottoms scarcely wider than the streams and abrupt slopes, showing that the present cycle of erosion is yet in its youth.

The streams of the area—Milwaukee, Menominee, Kinnickinnick, and Root rivers and Oak Creek—all pour their waters into Lake Michigan. The continental divide runs through the eastern part of Waukesha County and its proximity to the lake has so limited the drainage areas that none of the streams are of great size.

In consequence of the north-south trend of the lines of elevation, the streams, instead of following the general slope of the surface directly eastward to the lake, flow for considerable distances nearly parallel to the lake shore, and reach it eventually only by taking transverse courses at points where the continuity of the ridges is broken. Some of the streams reach the lake only after a series of shifts from one of the parallel valleys to another.

These features are well illustrated by the course of Milwaukee River. This stream takes its rise in Fond du Lac and Sheboygan counties, from a number of nearly parallel southward-flowing streams which gradually unite to form the main river. At West Bend the Milwaukee turns abruptly eastward. After passing Newburg it swings northward and then resumes its eastward course. Near Fredonia, when within 9 miles of the lake, it bends sharply to the right and flows southward, almost parallel to the lake shore, for more than 30 miles, to its debouchure at Milwaukee. Throughout the greater part of this distance its channel is within 3 miles of the lake shore, and at some points the shore is less than 1 mile distant. This somewhat anomalous course is due to the disposition of the parallel ridges bordering the lake and to the absence of east-west transverse valleys cutting through them, so that when the glacial barrier, to which the drainage at first became adjusted, was removed, the stream could find no other course than that to the south for a long distance. Not till the valley of Menominee River was reached at Milwaukee was the stream diverted to the lake. Except in the last 5 or 6 miles of its course the valley is generally broad, with slopes that are gentle and but little modified by erosion. The stretch covered by the lower 5 or 6 miles is sharply cut by erosion. Certain changes, which are noted under the heading "Geologic history," have taken place in the lower course of this stream. Its fall in the last 18 miles of its course is about 4 feet per mile. The stretch comprising the lower $2\frac{1}{2}$ miles—that is, the part below the Milwaukee dam—is utilized as a harbor. As this part of the river receives a large portion of the city sewage, it has been found necessary to flush the current in order to carry off the contaminated water. For this purpose a 12-foot tunnel has been constructed from a point 2 miles north of the harbor entrance through the intervening hill to the river just below the dam. Through this tunnel, by means of a 14-foot propeller wheel, 500,000,000 gallons of lake water may be driven every twenty-four hours. This addition to the river volume is effective in keeping the waters in a fair state of activity.

Menominee River has its origin in the southeastern part of Washington County, whence it flows in a southeasterly direction to Wauwatosa. From Wauwatosa it flows eastward 2 miles, then turns abruptly southward for 1 mile and again eastward for 3 miles to its confluence with Milwaukee River, three-fourths of a mile from the harbor entrance. The Menominee is a small stream, ordinarily scarcely a rod in width, except where widened and deepened in its lower course by dredging for harbor purposes. Above the mouth of Underwood Creek the slopes are gentle and the valley is not greatly modified by erosion. From this point to the lake the valley is of an erosional type, cutting across the topographic trend with abrupt slopes rising in places 100 feet or more above the valley bottom. In its lower 3 miles, lying east of the National Soldiers' Home, the valley averages one-half mile in width and has a flat, marshy bottom. Except in this lower part the gradient of the stream is high, the fall being 270 feet in 25 miles, an average of $10\frac{1}{2}$ feet per mile. A special sewage pumping works on Jones Island assists in the discharge into the lake.

Kinnickinnick River is a small stream, 5 or 6 miles long, in the southern part of the city of Milwaukee. As this stream receives a large part of the sewage of the southern part of the city it is flushed with water drawn from the lake through a tunnel extending under that part of the city known as Bayview. One of the tributaries of this transverse stream drains a large marsh occupying a depression between two of the lake-border parallel ridges. The southern part of this marshy valley is drained to the lake at South Milwaukee by Oak Creek, another small transverse stream. A like valley to the west, in the towns of Greenfield and Franklin, is drained partly northward by Underwood Creek to Menominee River and partly southward to the lake at Racine by the north branch of Root River.

DESCRIPTIVE GEOLOGY.

GENERAL RELATIONS OF THE SEVERAL FORMATIONS.

The uppermost geological formation of this region is the glacial drift, consisting for the most part of unconsolidated clay, in which are embedded pebbles and bowlders. Beneath the drift are indurated rock formations which may be seen at numerous quarries and natural exposures. Well borings that have penetrated to depths of several hundred feet have shown that the substructure of the area consists of a series of such formations, varying in thickness and alternating in character (see fig. 1).

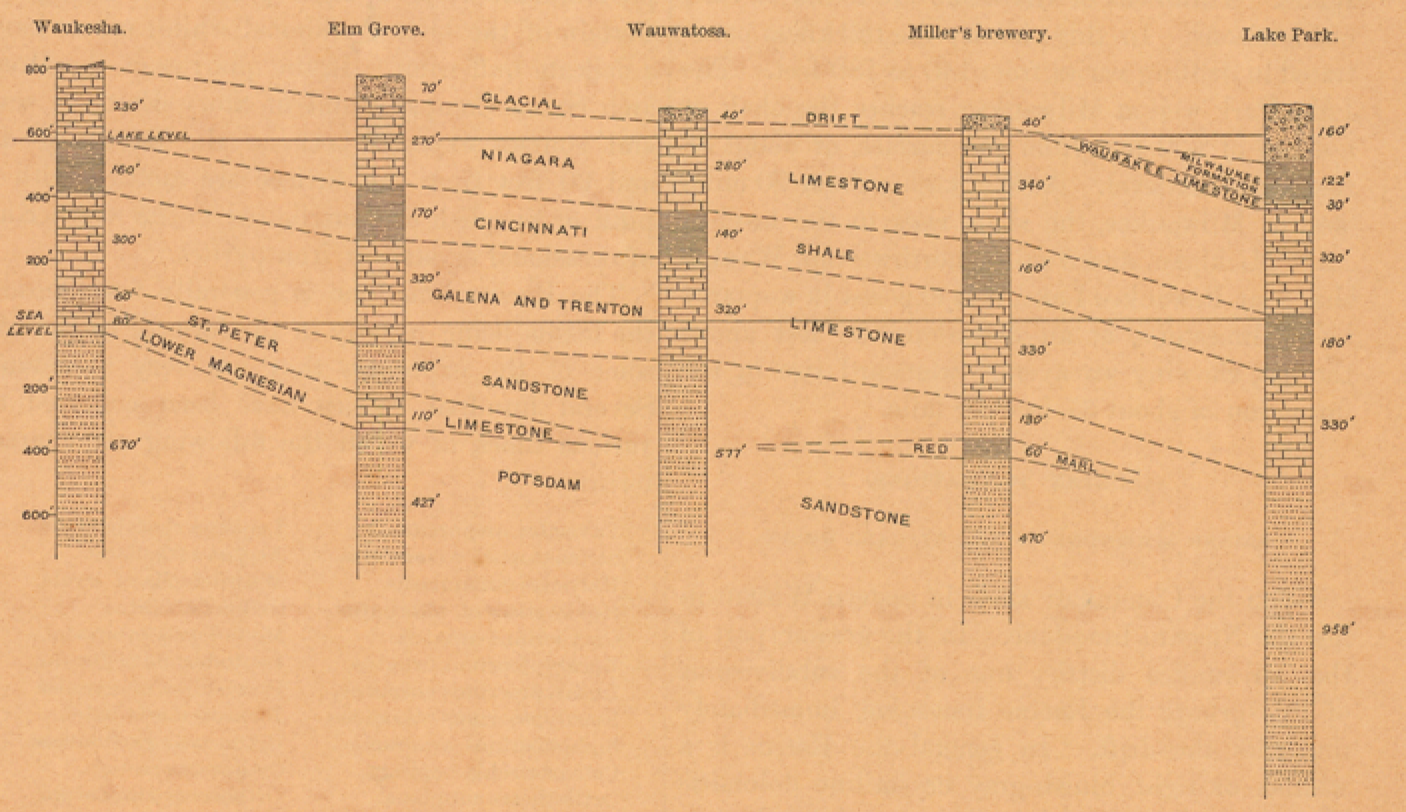


FIG. 1.—Artesian-well sections between Waukesha and Milwaukee.
Showing underground geologic relations.

The strata have a nearly uniform dip toward the southeast, so that, in their extension northwestward through Portage and Marathon counties, in the middle part of the State, they rise to the surface one after another, in the order of their succession downward. One traveling in this direction may note that each formation disappears as the next formation below rises to form the general rock surface, until even the lower sandstone has risen to the surface, spread over a great area, and disappeared in its turn. There then appear from beneath the sandstone still older igneous and metamorphic crystalline rocks. These are of pre-Cambrian age and immediately underlie the drift over an extensive area in the northern half of the State, forming a nucleus or island about which the sedimentary beds have been deposited.

Of the rock formations underlying the Milwaukee area those not exposed at the surface may be passed with but brief mention. The information concerning them is derived from the records of deep wells and from a general knowledge of the characteristics exhibited in those parts of the State where they are exposed to examination.

FORMATIONS UNDERLYING THE NIAGARA LIMESTONE.

The lowest of the rock formations which has been penetrated by deep wells of the Milwaukee district is a sandstone of considerable areal extent, which has been commonly known in this and adjacent regions as the Potsdam[1] sandstone of the Cambrian system. Samples of drillings show it to be of the same general character beneath this area as in those parts of the State where it is exposed at the surface. It is principally a quartzose sandstone, but varies in composition and texture, ranging through all grades of rock from fine-grained arenaceous and calcareous shale or fine-grained sandstone to very coarse sandstone of almost pebbly consistency. It is well indurated at some places, especially in the upper part of the formation, where it is cemented by calcareous material; at other places it is little more than an accumulation of well-rounded, incoherent quartz-sand grains.

Samples of drillings from the wells show a beautiful variation in color, the greater part being very light colored, buff to white, but with grays, browns, and reds of several shades. Here and there the occurrence of soft beds of reddish, bluish, or greenish shaly material is reported, and rarely thin beds of magnesian limestone have been encountered.

The limestone member, which is generally present in the upper part of the formation in the vicinity of Madison, Wis., has not been reported as occurring in the area under discussion. Some of the wells encountered near this horizon beds of soft reddish calcareous material, spoken of by the well drillers as "red marl." The well at Mr. Fred Miller's brewery (fig. 1), in the Menominee Valley just west of the city, is said to have penetrated 60 feet of this "red marl." Mr. Dixon's well, $1\frac{3}{4}$ miles farther south, also passed through considerable "red marl" at this horizon, one bed of which was 40 feet thick. The well at the E. P. Allis Company's works, near Milwaukee Harbor, penetrated 70 feet of similar reddish material, though this lay below a greater thickness of sandstone than that in the other wells. From the position of the "red marl" in Miller's well it might be inferred that it represented the Lower Magnesian limestone. Judging from the occurrences at other points, however, it appears more probable that the "red marl" belongs in the Cambrian. The full thickness of these Cambrian deposits is not known, inasmuch as none of the wells of the area have passed entirely through the formation. The well at Mr. Fred Miller's brewery is said to have penetrated 470 feet of sandstone below the "red marl."

Above the Cambrian sandstones generally throughout eastern Wisconsin lies a limestone known as the Lower Magnesian limestone. The well at the convent in Elm Grove penetrated 110 feet of this rock, and its presence is also shown by the log of the city wells in Waukesha, 8 miles farther west. It is reported, however, that none of the wells in Milwaukee or in Wauwatosa encountered limestone at this horizon. This formation is hard, cherty, magnesian limestone of dirty grayish-buff color and very uneven texture.

Upon the uneven surface of this limestone lies the St. Peter sandstone, which is soft, friable, quartzose, and usually white or light buff in color. Owing to the unevenness of the floor upon which the sands were laid down the formation varies considerably in thickness from point to point. At some places it is so thin as scarcely to cover the thicker parts of the limestone; at other places where the limestone is thinner the sandstone thickens. Where the limestone is absent the drill passes immediately from the sands of the St. Peter formation to those of the Cambrian, with no intervening beds to mark the horizon. Thus the well

[1] The terms Potsdam, Lower Magnesian, Trenton, Cincinnati, and Niagara are used in accordance with the nomenclature appearing in the reports of the Wisconsin Geological Survey, the correlation of the formations with others outside of this area not being here considered.

at Lake Park, Milwaukee, is said to have penetrated more than 950 feet of continuous sandstone below the base of the Trenton limestone. By far the larger part of this undoubtedly belongs to the Cambrian system. Where separated from the lower sandstone by intervening beds in this vicinity, thicknesses of 45 to 160 feet of this upper sandstone have been reported.

The St. Peter sandstone is overlain by the buff and bluish Trenton and Galena limestones, whose combined thickness varies from 245 to 330 feet.

On the Galena limestone lie the shales and shaly limestones of the Cincinnati formation. In places the shales are little else than slightly indurated greenish and bluish clays. The clays are often very fine grained, containing but little sand or other hard material, and grade into a variety of impure shales. Thin beds of limestone are found at various horizons. In this vicinity the thickness penetrated in drilling varies from 140 to 180 feet. The Lake Park well at Milwaukee reaches the shale at a depth of 632 feet from the surface, or about 38 feet above sea level. At Waukesha, about 20 miles west of Milwaukee, the shale rises to the level of Lake Michigan, and 5 miles northwest of Waukesha, near Pewaukee Lake, it is exposed in a quarry below limestone, at an elevation 860 feet above the sea, showing an average westward rise in the formation of about 37 feet per mile.

SILURIAN FORMATIONS.

RACINE LIMESTONE OF THE NIAGARA GROUP.

Upon the Cincinnati shale in eastern Wisconsin lies the Niagara limestone. In the greater part of the Milwaukee district one of the subdivisions of this group, the Racine limestone, immediately underlies the drift. In general the Racine is a whitish or light bluish-gray crystalline dolomitic limestone. In this vicinity it is usually well stratified in regular, little-fractured courses, which thicken from a few inches at the top downward to about 28 inches at the bottom of the main exposures. The rock varies in different courses from granular limestone of irregular, open, porous texture, to even, dense, fine-grained rock of conchoidal fracture.

An interesting feature of the rock exposed in the quarries between Milwaukee and Wauwatosa is the alternation of fine- and coarse-grained strata. The finer-grained strata are of compact texture, with conchoidal fracture. Alternating with these are beds of more or less irregular, coarse, granular, or lumpy texture. The rock of these beds is peculiar. Under the hammer it breaks into angular lumps or granules, varying in size from that of a pea to that of a hazel nut. In some layers a rather loose buff calcareous material fills the interstices between the harder granules. On weathering this filling dissolves, leaving an irregular, open texture. Other layers show an irregular, semilaminate structure, and in these, when the rock is split into building blocks, the bedding surfaces are curiously uneven, with small, irregular knobs and hollows, the knobs having about 1 inch relief. These strata are very hard and do not break readily across the planes of stratification. There are five or six beds of this character in the quarry sections. Between two layers of this kind are several strata of the even-textured, fine-grained rock. Throughout the greater part of the formation these different kinds of rock are arranged in distinct strata, yet at some horizons there are gradations from one type to the other within a single stratum. In some places a thin layer of the coarse, irregular-textured rock runs through the middle of a fine-grained, even-textured stratum with gradations upward and downward. At the quarry of the Story Brothers the coarse-textured layers here and there pinch out laterally and are replaced by soft blue shale.

Another notable feature of the Racine limestone of the Milwaukee district is the occurrence of mounds of massive, coarse-grained rock, showing no signs of bedding, in the midst of regularly bedded limestone. In places the cores of these mounds appear to be a breccia of angular fragments of limestone in a limestone matrix.

When traced laterally from the center of one of these mounds, the rock is seen to pass gradually into more or less definite layers that dip away from the center of the massive accumulation (see fig. 10). The dip where first apparent may be as high as 30°, but becomes gradually less toward the periphery of the mound. The change in dip is accompanied by a change in the character of the rock, so that within a few rods of the place of the initial appearance of bedding, one finds rock of the usual character in nearly horizontal layers. The local dip in the bedding of the stratified rock on the flanks of the mounds appears to be due not to upheaval, but to the original slope of the deposits, inasmuch as the bedded rock does not merely lie upon the flanks of the mounds, but actually grades into the massive unstratified rock forming the cores of the elevations.

The color of the stone is about the same at all of the exposures, though it differs somewhat in the various beds exposed in the larger quarries. The predominant color is light gray or bluish gray. Certain of the beds are almost white; others have a delicate buff color. In the quarries of the Monarch Stone Company and of Story Brothers several courses exposed between the depths of 45 and 60 feet from the surface are mottled with a pink or purplish tint, attributed to the weathering of occasional crystals of iron pyrites.

The Racine limestone is generally fossiliferous, the fossils being usually in the form of casts. At some of the exposures they are very abundant. Several hundred species have been collected at various times, of which the following are characteristic:

Favosites niagarensis.	Leptæna rhomboidalis.
Stromatopora concentrica.	Atrypa reticularis.
Halysites catenulatus.	Whitfieldella cf. hyale.
Holocystites cf. alternatus.	Orthis flabellites.
Caryocrinus ornatus.	Modiolopsis subovata.
Eucalyptocrinus ornatus.	Leptodornus neglectus.
Eucalyptocrinus cornutus.	Platystoma niagarense.
Eucalyptocrinus obconicus.	Pleurotomaria halei.
Siphonocrinus armosus.	Orthoceras carltonense.
Camarotœchia neglecta.	Orthoceras rectum.
Orthothetes subplana.	Orthoceras annulatum.
Spirifer eudora.	Lituites graftonensis.
Spirifer radiatus.	Calymena niagarensis.
Spirifer nobilis.	Illænus armatus.
Stropheodonta profunda.	Illænus ioxus.
Pentamerus oblongus.	Illænus insignus.
Pentamerus bisinuatus.	Sphærexochus romingeri.

With the exception of those flanking the limestone mounds the beds have usually very slight dips, rarely more than 2° to 5°. Locally there are slight variations, but the prevalent dip is to the east or to the southeast. Though broken by joint planes, and in some places showing slight displacements of a few inches along these planes, the beds generally afford no evidence of disturbance in position.

The average thickness of the Racine limestone in the Milwaukee district, shown by the records of eight wells that were drilled through it, is about 320 feet, the least thickness thus shown being 267 feet and the greatest 425 feet. In but one of these wells is this limestone so overlain by a subsequent rock formation other than the drift as to show that none of the original thickness was removed by Glacial or pre-Glacial erosion. This is the well in Lake Park, where a thickness of 320 feet is reported for this formation.

The distribution of the Racine limestone throughout the Milwaukee district where it is not overlain by subsequent formations other than the drift is shown in fig. 2. The exposures within this area are shown on the areal geology map.

The Racine limestone is well exposed in the quarries in the Menominee Valley between Milwaukee and Wauwatosa. The rock seen in these different quarries, which are separated by distances of one-fourth and one-half mile, is very similar. At the time of the writer's visit thicknesses of 40, 70, and 100 feet were exposed at the several places (fig. 12). The stone is distinctly bedded in regular courses, which thicken from the top downward, the thicknesses ranging from 4 to 28 inches. The character of the rock and the alternation of fine-grained and coarse-grained, uneven-textured rock of the quarries of the Monarch Stone Company and of Story Brothers is described above. In the lower part of Story Brothers' quarry, where the uneven-textured layers pinch out and are replaced by thin beds of soft bluish shaly material, there are other layers of impure argillaceous rock that run into seams and pockets of soft blue clayey shale. This is highly impregnated with iron pyrites. Where these pockets occur the overlying limestone strata have sagged so as to produce fractures.

At this quarry there is a slight dip toward the southeast. At Manegold Brothers' quarry the slight dip is toward the northeast. Slight faulting also occurs, the major faulting being along joints striking N. 50° E., the other set striking N. 70° W. The throw of the faults at Story Brothers' quarry is 2 or 3 inches. The major vertical joints strike N. 56° W. and N. 50° E. These are 4 to 20 feet apart, and as the rock is not otherwise fractured stones of large dimensions are readily quarried.

The mounds of limestone to which reference is made above occur at three points marking the apices of an oblique triangle, whose area includes the quarries of Story Brothers, Manegold Brothers, and the Monarch Stone Company. The first of these mounds to be described here is situated in the north side of the Menominee Valley at the foot of Washington avenue, at a point about 1¼ miles southeast of Story Brothers' quarry. This is on the site of Mr. Moody's old quarry. The section here exposed is about 20 feet in height and 60 feet in breadth. The upper surface of the rock has a regularly rounded form and the top, which projects slightly from the superjacent clays, curves downward and backward under the slope, showing that this is a section of a mound of limestone. On the west side the rock is somewhat bedded toward the top, but as a whole it is massive. In places it is much broken, possibly by blasting, but the middle part is solid. The rock is a hard, gray, rather coarse-grained dolomite, exceedingly irregular in texture. This exposure has yielded many fossils.

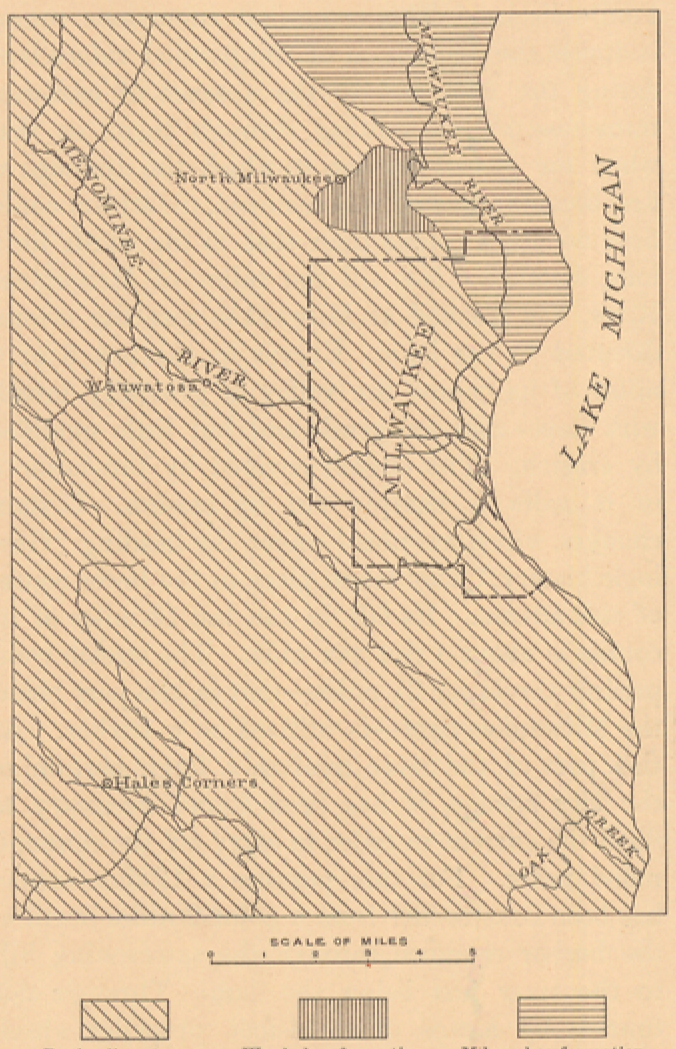


FIG. 2.—Sketch map of Paleozoic formations of the Milwaukee special quadrangle.

Bed rock heavily covered by drift and only occasionally exposed.

One and one-fourth miles west of the mound just described, in the grounds of the National Soldiers' Home, at the bend of the Menominee Valley, the slope is marked by a prominent drift-capped mound that rises about 80 feet above the valley floor. On the northeast side the lower 35 to 40 feet is a vertical section of rock. How much the rock rises under the drift is not known, but a well on the flat to the east is 20 feet deep and does not reach the limestone, and the deep well at the buildings about 100 yards to the west of the slope reaches limestone at a depth of 96 feet—73 feet lower than it is exposed in the slope. This, then, appears to be a second mound, rising considerably above the surrounding rock surface. The rock here is a massive gray dolomite of uneven, coarse, granular texture, showing no evidence of bedding.

About 1¾ miles farther northwest, at a point 2½ miles from Moody's quarry, there is a third exposure, at the old quarries of Schoonmaker and Busack. At Busack's quarry the limestone strata are exposed in the valley floor, in a nearly horizontal position. The beds are heavy, well defined, and slightly argillaceous, but of rather fine, even grain, with conchoidal fracture. Interstratified with these are layers having the lumpy structure seen at Story Brothers' quarry. In places the rock is really a conglomerate, in which the pebbles and the matrix are of the same material and blend in solidification. Toward the east the strata begin to rise gently, at the same time dipping laterally at slight angles, as if riding over an east and west axis. At this point there is a break in the section. A point of the hill has been left, so that the clay slope comes down into the valley. The interval is barely 2 rods, but when the rock beds reappear on the east side of this point, they are rising at an angle of 30°, the dip indicating, as before, an east-west axis, over which the beds are deposited. Before the rock passes under this covering of clay a change occurs in its character. Near the east end of Busack's quarry the upper layer becomes slightly irregular in bedding and rather soft and granular in texture. At the west end of Schoonmaker's quarry, the stratification of the rock seen emerging from beneath the clay covering soon becomes obscure and passes into a massive irregular structure, with no evidence of bedding. This change takes place not only from east to west but from north to south. The view in fig. 10 shows a north-south section at the west of Schoonmaker's quarry, with the strata rising from south to north and passing into the irregular-textured massive rock that forms the body of the mound. When visited by the writer the lower part of the excavation was filled with water, so that the lower beds were not accessible. The upper 25 to 30 feet of the rock is exposed in the valley slope for about 100 yards to the east, except where obscured by clay washed down from above. The rock is a massive, coarse-grained, hard bluish-gray dolomite. In places it appears to be a breccia of angular fragments of limestone in a limestone matrix. Toward the east end the upper part is more nearly buff in color and is impure and porous, containing much clay. The section is evidently that of an elongated mound or ridge of limestone whose elevation is due not to upheaval and folding of the beds but rather to the mode of its formation.

About 1 mile northwest of North Milwaukee a small quarry has been opened in Racine limestone on the Frederick A. Zautcke estate. When visited by the writer there was an exposure of 6 to 10 feet of limestone which appears to belong to another of these mounds or reefs. The upper 6 feet exposed is composed of massive, irregular-textured, open, porous dolomitic limestone of grayish color. There are many small holes in the rock and fossils appear to be plentiful. A 4-foot hole in the bottom of the quarry exposed rock of rather more definite bedding. This rock is rather rough textured, of uneven fracture, very hard, and mottled bluish gray and brownish gray in color. Numerous specimens of *Illænus* were seen.

At Zimmerman's quarry, in the valley of Menominee River, 3 miles northwest of Wauwatosa, there is an exposure of 25 feet of buff thin-bedded limestone, probably the upper part of the Racine limestone. The strata are thin and shelving at the top, but thicken from 3 to 6 inches at the bottom. The bedding is nearly horizontal, undisturbed, and but little fractured. The rock is an even-grained dolomite, weathering from light gray to buff. It shows in places minute pores containing pitchy asphalt, with but few fossils.

About 3 miles farther north is a small mound of open, porous, much-weathered limestone, containing gasteropods, brachiopods, and corals.

One mile east of Hales Corners, on the west side of Root River Valley, is the old limekiln and quarry belonging to the Trimbone estate. Here there is exposed a 10- to 25-foot section but thinly capped with drift. The rock face, which is now considerably weathered, shows thin beds at the top, thickening to 1 to 3 feet at the bottom. For the most part the rock is of uneven, open, porous texture and contains many fossils. Where most irregular in texture the rock is massive, showing little evidence of bedding. The strata dip S. 20° W., at angles of 7° to 11°, so that the gentle valley slope cuts across the edge of the strata. Rock of the same character is exposed at Mr. Anderson's small quarry one-fourth of a mile south.

There are small outcrops and a quarry on the east side of Root River Valley, 3 miles a little south of east from Hales Corners; also three small outcrops 1 to 1½ miles farther south, in the same valley.

WAUBAKEE FORMATION OF THE CAYUGA GROUP.

The Racine limestone of the Milwaukee district is overlain by certain beds of rock concerning whose age there is lack of positive evidence, owing to the scarcity of determinable fossils within them. Their stratigraphic position is above the Racine limestone and below the Milwaukee formation of the Hamilton group. In their position above the Racine limestone, and in their lithological character and chemical composition, these strata closely resemble certain beds exposed about 20 miles north of Wauwatosa, near the village of Waubakee, in Ozaukee County, which have been correlated on faunal evidence with a portion of the Cayuga group of New York. On the basis of this resemblance, for want of better evidence, these beds in the Milwaukee area have also been provisionally referred to the same formation.

The deposits are best exposed at Mr. Emil Petzold's quarry on Mud Creek, 1 mile south of North Milwaukee. The same beds are exposed one-fourth of a mile farther west, on the same creek. The rock is gray to brownish-gray, finely laminated magnesian limestone, splitting readily into slabs one-half inch to 4 inches thick. A thickness of 10 to 12 feet is exposed. The lower strata are more unevenly bedded and contain streaks of blue clay. In general the strata are very nearly horizontal, but at the western exposure they dip 5° toward the east.

Beneath the "cement" rock at the quarry of the Milwaukee Cement Company, in the valley of Milwaukee River one-half mile north of the city limits, is a porous brownish limestone believed to be the continuation of the rock seen at Petzold's quarry 2½ miles west. Only the undulating upper surface and 1 or 2 feet in the section have been exposed, and no fossils have been found, so that the identification is based chiefly on stratigraphic position and chemical composition. Analyses of the rock forming the floor of the Milwaukee Cement Company's quarry and of that at Petzold's quarry showed very slight difference in composition except in the content of oxide of iron, which is somewhat higher in the rock from the bottom of the cement quarry, giving the brownish color. It is also reported that a brownish limestone underlies the cement rock at the quarry of the Consolidated Cement Company on the shore of Whitefish Bay. It is, however, not well exposed for examination.

In the boring for the artesian well at Lake Park 30 feet of brownish limestone was found at a depth of 282 feet below the surface, or about 204 feet below the level of the lake. This brownish limestone here lies immediately above the rocks of the Niagara group.

The test borings for the intake tunnel at North Point also show 10 feet of brownish stone between the Hamilton beds and the Niagara groups. There seems to be little doubt as to the identity of the brownish limestone shown by these several borings with that which forms the floor of the cement quarries.

The only fossils reported from this formation near Milwaukee were collected from the exposures on Mud Creek. These are fair specimens of *Meristella neucleolata*, a *Rhipidomella* resembling a young *R. oblata*, and an imperfect specimen of *Meristella* or *Pentamerus*.

DEVONIAN FORMATIONS.

MILWAUKEE FORMATION OF THE HAMILTON GROUP.

The deposits referred to the Hamilton occur in the northeastern part of the Milwaukee area, as shown in fig. 2. For the most part the formation is heavily covered with drift and only the lower 15 to 25 feet is exposed to direct observation. The records of drillings and excavations, however, show the presence of a much fuller series of beds than is now exposed at any place. As nearly as can be determined the order and the maximum thickness of these beds are given in the following generalized section:

Generalized section of Devonian beds near Milwaukee, Wis.

	Feet.
Black shale	15
Soft bluish "soapy clay" or shale	80
Bluish magnesian limestone, "cement" rock	12
Bluish limestone and softer bluish "soapy clay"	31

So far as there has been opportunity for observation, these beds, with the exception of the upper black shale, are highly fossiliferous, showing a great variety of invertebrate forms as well as plates and teeth of armor-plated fishes. These fossils are in part silicified, in part pyritized, and in part are casts. Beneath this group of beds is the brownish limestone provisionally referred to the Cayuga group.

The best exposure of beds belonging to this formation is afforded by the quarries of the Milwaukee Cement Company (fig. 13), in the valley of Milwaukee River, one-half mile north of the city limits. Here there is a 25-foot section resting upon the brownish limestone already described. The rock here is a bluish hydraulic limestone, rich in magnesia, alumina, iron, and silica and showing abundant fossils. The lower 15 feet is rather soft and in places very soft and shaly. Above is a very hard stratum 6 feet thick, and at the top is 4 feet of shaly rock, readily disintegrating on exposure, but with thin, hard layers bearing silicified fossils. The top of this section is 30 feet above Lake Michigan. The strata are very slightly undulating, with a gentle dip toward the southeast. The rock forms the bed of the river for some distance above the cement quarries and also southward to the Washington Street Bridge.

Three miles north of the quarries of the Milwaukee Cement Company, at the foot of the bluff on the shore of Whitefish Bay, is an exposure of the Milwaukee formation a few feet above the water's edge. Near this point the Consolidated Cement Company has opened a shaft to supply its mill upon the bluff above. This shaft extends to a depth of 22 feet below the level of the beach, where it connects with a main gallery which, at the time of the writer's visit, extended 210 feet in a north-south direction. From this gallery drifts were being extended to the west in the working beds. The upper 5 or 6 feet is left as roofing and is not well exposed to examination, but material thrown out in excavating the shaft through these showed them to be of moderately hard, fine-grained, bluish-gray hydraulic limestone, characterized by an abundance of pyritized fossils, crystals of pyrite and of calcite, and traces of bitumen. The working face, which has a maximum height of 14 feet, shows dense, bluish-gray, massive to heavy-bedded magnesian limestone, having the same general appearance as that at the quarries on the river, but less distinctly marked bedding planes. So far as could be seen this part seems to be less fossiliferous than the beds composing the roof and those exposed along the river. The bedding is slightly undulatory, so that, though the general dip of the formation is toward the southeast, there is a slight dip to the west in the northern part of the exposure.

Between 1885 and 1900, in extending the water system of the city of Milwaukee, a shaft was sunk 130 feet deep on the beach at the North Point pumping station, and from the bottom of this shaft an intake tunnel was projected under the lake for a distance of 3200 feet. Preliminary to this work test borings were made which showed that below the lacustrine deposits and the drift the beds of the Hamilton group occur in fuller series than at the quarries on the river. At a depth of 42 feet below the water level, as shown by the records in the city engineer's office, the shore shaft penetrated 15 feet of black shale. Below this in succession were 40 feet of soft blue shaly rock, 10 feet of cement rock, and 31 feet of blue shaly rock. At a depth of 138 feet "brown stone and lime rock" were reached. The "lime rock" was penetrated to but a small depth, so that its identification is not positive, but it seems probable that the brown stone is the same as that in the bottom of the quarries on Milwaukee River and at Petzold's quarry on Mud Creek, while the "lime rock" is the Racine limestone.

The 8-foot intake tunnel was projected through the lower bed of shaly rock, so that the material excavated from the tunnel and from the shaft, which was dumped upon the beach near by, gave opportunity for examination and identification of the beds of the group. This has since been spread out on the beach and is now largely covered by the soil, grass, and trees of a small park, so that there is little chance to examine it further. The softer part is a lumpy, nodular shale, of greenish-gray color, soft when wet but hardening to a shaly rock when dry and readily disintegrating to clay on exposure to the weather. It strongly resembles the material seen on the shore of Whitefish Bay and some of the lowest and highest beds at the cement quarry on the river.

Portions of the blue shale carry fossils in an excellent state of preservation, of the same species, for the most part, as those found at the two exposures. Other portions are almost wholly devoid of fossils. In this they resemble some of the softer layers near the bottom of the cement quarry. (Monroe, C. E., and Teller, Edgar E. The fauna of the Devonian formation at Milwaukee, Wis.: Jour. Geol., vol. 7, 1899, No. 3, p. 272.)

The material dumped on the beach also showed harder portions, similar in color to the harder cement rock, but traversed by hard, white, siliceous seams. These seams are full of fossils, most of which are found in the Milwaukee Cement Company's quarry. There is no question as to the identity of the beds here found. The blue shale and cement rock are shown both by the shore shaft and by a boring 2060 feet from the shore line, with the difference that in the latter the underlying brownstone has declined to a depth of 180 feet below the lake surface, and the lower bed of the shale has thickened to 60 feet. The cement rock continues at the same thickness, having declined but 10 or 12 feet. The upper bed of blue shale has thinned to 15 feet, and the black shale is no longer seen, evidently having been removed by erosion. Five other borings at varying distances, up to 3200 feet, from the shore shaft show the presence of the blue shale and cement rock, but none show the black shale. One boring, 1500 feet from the shore, shows but 19 feet 4 inches of the lower blue shale yet remaining over the limestone, the whole superjacent thickness of the group having been removed by erosion and displaced by drift.

The log of the artesian well at Lake Park, near the crest of the bluff, 1 mile north of the North Point pumping station, shows the beds of the Milwaukee formation with the exception of the upper black shale, which has here been removed by erosion. The beds immediately underlie the drift and are reached about 80 feet below the lake level.

The succession here, beginning at the top, is as follows:

Partial log of well at Lake Park, Milwaukee, Wis.

	Feet.
QUATERNARY:	
Red clay, lacustrine or g'acial.	
Drift (sand, gravel, and till)	160
DEVONIAN:	
Hamilton (Milwaukee formation):	
Soft shale, 80 feet; "Cement rock," 12 feet; Soft shale, 30 feet	122
SILURIAN:	
Cayuga (Waubakee formation):	
Brown limestone	30

The city engineer's profile of the deposits penetrated by a series of test borings made along the line of Glen avenue from the North Point pumping station to Whitefish Bay also shows beds of this formation beneath the drift. Three of the borings penetrated about 10 feet of black shale, overlying blue shale. Elsewhere the black shale is absent, probably having been removed by erosion. As is noted in a subsequent connection, considerable amounts of this black shale are present as fragments in the drift at some points. All the borings but one show the presence of the upper bed of blue shale. On comparing the section afforded by these drill holes with the log of the Lake Park well and with that of the shore shaft, it appears probable that the "lime rock" reached but not penetrated by these borings is the same as the "cement rock" of the Lake Park well and of the borings for the intake tunnel and as the heavy stratum seen in the cement quarries on the river.

Mr. A. S. Nusbaumer informed the writer that the well at Welcome Park, west of Whitefish Bay, penetrated 110 feet of "cement rock" below 141 feet of drift.

A cut on the Milwaukee and Northern Railway just south of Brown Deer station, 5 miles north of North Milwaukee, exposed Devonian rock of the same formation. The rock here slightly exposed is thin-bedded, buff, very fossiliferous limestone, and the drift above contains abundant fragments of the same rock. The rock is much more weathered and decomposed than at the other exposures, but the abundant fish remains, brachiopods, and pelecypods indicate that the horizon is the same. Rock also occurs in the bed of Milwaukee River at several points, but is nowhere conveniently exposed for examination.

Professor Chamberlin described an occurrence of Devonian rock at Granville Center, which is no longer accessible. Concerning this he makes the following statement (Geology of Wisconsin, vol. 2, p. 391.):

"In the northwest quarter of section 10 and in the northeast quarter of section 9 of the town of Granville we find the most northwesterly known exposure of the . . . Hamilton formation in the brow of a hill facing the northwest. Only 36 paces down the gentle slope from the Hamilton beds a pit has been opened which discloses the Niagara limestone. The vertical distance between the top of the Niagara exposed and the bottom of the quarry of Hamilton rock is about 6 feet. The intermediate slope is largely occupied with old pits, now filled, but in the material thrown from them only Niagara and Hamilton rocks were seen. In the gutter of the adjacent road both the Hamilton and the Niagara are shown, with a vertical distance of less than 5 feet between them. In the abundant chip stone of the gutter there is none of the shaly limestone [Waubakee]. But it is a rock peculiarly liable to break up into chip stone, and is abundant in the drift near known outcrops, and in the line of the drift of them. In view of all of these facts the shaly limestone [Waubakee] must be regarded as absent at this point."

The strata of the various localities near Milwaukee have not been fully correlated with those of the cement quarries on the river, but the fauna represented is much the same so far as found. The upper black shale shows only two or three species, among them *Lingula*, the simplest and most persistent of the brachiopods. The abundance and variety of marine life of this period is shown by the fact that though the fauna of the shale revealed by the borings and the excavations of the intake tunnel is imperfectly known, yet the Hamilton beds of this vicinity have already yielded nearly 200 species, some of which are named in the subjoined list:

Fossils of the Hamilton beds.

Fenestella sp.
Stictoporina cf. claviformis.
Orbiculoidea lodiensis media.
Craniella hamiltoniæ.
Chonetes scitula.
Pholidostrophia iowensis.
Leiorhynchus kellogi.
Spirifer iowensis.
Spirifer angusta.
Spirifer andaculus.
Spirifer fornacula.
Spirifer subvaricosa.
Delthyris cf. ziczac.
Meristella sp. undet.
Schizophoria striatula.
Athyris fultonensis.
Orthothetes chemungensis arctostriatus.
Paleoneilo emarginata.
Paleoneilo brevis.
Modiomorpha putillus.
Conocardium sp. undet.
Pterinopecten vertumnus.
Conocardium cf. cuneus.
Tentaculites bellulus.
Bellerophon sp.
Macrocheilus hamiltoniæ.
Callonema sp.
Loxonema minuscula Hall.
Eunema speciosum.
Gyroceras eryx.
Gomphoceras cf. eximium.
Stropheodonta demissa.
Stropheodonta perplana.
Atrypa reticularis.
Cyrtina hamiltonensis.
Neucleospira concinna.
Gomphoceras breviposticum.
Nautilus sp.
Proetus sp.

QUATERNARY FORMATIONS.

PLEISTOCENE DEPOSITS.

CLASSES OF DEPOSITS.

Upon the indurated rock formations throughout a large part of the northern half of the North American continent lies a mantle consisting of unconsolidated deposits of various kinds, formed during the Quaternary period. These deposits may be grouped into three classes, depending upon the conditions of their deposition. The deposits of two of these groups were formed during the Pleistocene epoch. Of these the first class includes the glacial deposits, which were formed either directly through the agency of great sheets of glacier ice which overspread the region or were made by waters associated with these glaciers and in large part derived from the melting of the ice composing them. With these are grouped certain other deposits made through the combined action of glaciers, water, and wind. A second class includes such deposits as were formed by various agencies during intervals when the land was free from the dominance of the sheets of ice; these are the interglacial deposits. A third class of Quaternary deposits includes all those accumulations of material which have been formed in different ways since the latest disappearance of the great ice sheets, comprising the post-Glacial or Recent deposits.

GENERAL CHARACTER OF THE GLACIAL DRIFT.

The drift consists of all those materials gathered up by the glaciers during their advance across the country, transported greater or less distances, and finally deposited by being released from the grip of the ice transporting them.

Good exposures of the glacial drift of the Milwaukee district are plentiful and easy of access. The lake bluff, where not covered with vegetation, gives an extended section 20 to 140 feet in height. The same is true of the abrupt slopes of Milwaukee River valley from the cement works southward and of the Menominee Valley from Wauwatosa to the lake. Wagon roads and railroad cuts and temporary exposures in excavations may be seen at many places.

These exposures show many stratified deposits of sand, gravel, and clay, but the larger part of the drift is unassorted (fig. 14), consisting generally of a matrix of bluish or reddish clay in which are embedded stones of all sizes, shapes, and kinds. The clay is highly calcareous, such as would result from the abrasion of limestone and calcareous shales. The stony material embedded in the clay ranges from fine gravel to bowlders weighing several tons. For the most part these pieces of rock are less than a foot in diameter, but bowlders 2 and 3 feet in diameter are seen, and more rarely bowlders 5 to 10 feet through. These bowlders could not be transported by water currents of any ordinary strength unless they were frozen in blocks of ice.

The arrangement of the greater part of the drift is most heterogeneous, fine and coarse material, clay and bowlders, being intimately mixed. This is in striking contrast with the assorted and stratified beds of water deposition. Yet from the frequent occurrence of stratified material in this deposit, it is evident that considerable water must have aided in its deposition.

The pebbles and bowlders of the unstratified drift, in contrast with those of stones worn by fluvial or lacustrine waters, are partly angular, partly rounded, but mostly subangular in form, with numerous flat faces or facets. The facets usually show the polishing and parallel grooving and scratching that are produced when pebbles are firmly held in various positions and rubbed over hard and gritty surfaces (fig. 15).

While the clay matrix of the drift is highly calcareous, showing that it is largely derived from limestone and calcareous shales, such as immediately underlie the drift of this region, examination with a microscope shows a considerable percentage of grains of a variety of minerals, such as result from the abrasion of crystalline rocks. Also an examination of the coarser material of the drift, the pebbles and bowlders, shows that while 80 or 90 per cent correspond in character to the rock underlying the drift in this area, the remaining 10 or 20 per cent consist of sandstones and crystalline rocks of many kinds, wholly foreign to this part of Wisconsin.

At most places in this area the surface of the rock also, when stripped of its covering, shows well the effects of abrasive action. Instead of the gradation from solid rock to incoherent soil characteristic of those regions where the soil is the residuum from the disintegration of the underlying rock, there is usually a sharp line of separation between the surface of the bed rock and the overlying drift. Unless the upper rock beds are thin and shelving and more or less broken up, they usually have smoothed and polished surfaces, marked by grooves and scratches similar to those on the pebbles and bowlders of the drift. If the rock surface has not long been exposed to recent weathering the striations are sharp and distinct. At some places they are continuous for several yards, but usually they are shorter. They are in some localities almost perfectly straight; in others they are curved, broken, or jagged. They are usually nearly parallel at any given place, or cross at low angles.

Where there are slight inequalities in the surface, such as protruding knobs or jutting ledges, it is found that the side facing east or northeast is smoothed and polished, while the opposite side is rougher and more or less unmodified. In small, sharp depressions the east or northeast side is rough while the west or northwest side is smoothed.

When all the glacial phenomena of this and adjacent regions are taken into consideration it becomes apparent that the glaciers depositing the drift came from the north, moving southward along the Lake Michigan trough and spreading thence over the surrounding areas. On retracing the course of this movement it is found that not within 250 miles are formations known to occur from which the foreign rock constituents of the drift could have been derived. The sandstones and crystallines and copper-bearing rocks over which the glaciers passed occur in the Lake Superior region of northern Michigan and Canada.

GLACIAL AND INTERGLACIAL STAGES.

The great North American ice sheets appear to have had more than one center of growth. One main center lay east of Hudson Bay and another

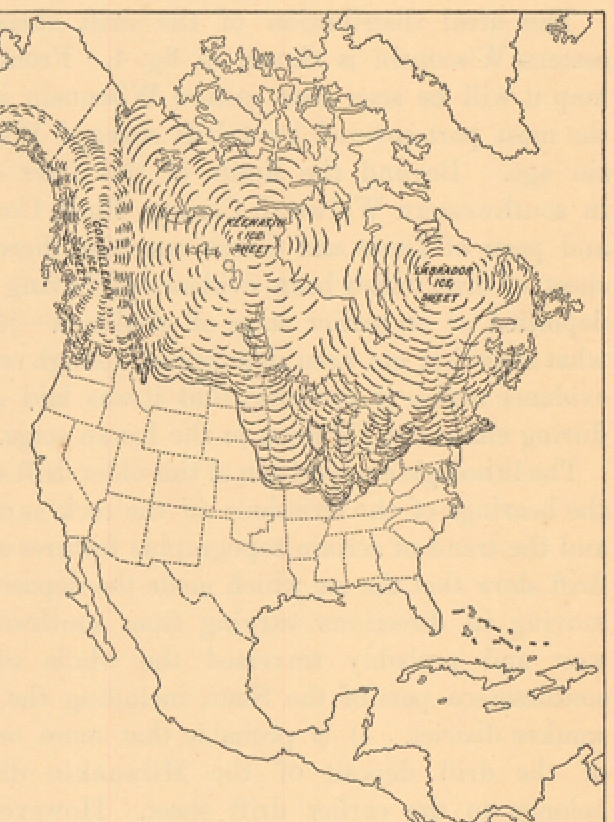


FIG. 3.—Map of area covered by the North American ice sheet of the Glacial epoch at its maximum extension, showing the approximate southern limit of glaciation, the three main centers of ice accumulation, and the driftless area within the border of the glaciated region.

west of it (fig. 3). There were perhaps other minor centers. Ultimately the snow fields extending from various centers united and the resulting ice sheet is spoken of as a unit. Other smaller ice caps occurred in the West and Northwest, but the present discussion has to do only with deposits made by the ice of the main sheet.

So long as the rate of accumulation of the ice sheet exceeded the waste by melting and evaporation the ice continued to advance, but when a region was reached where the waste equaled the rate of advance the margin halted. When the waste exceeded the advance the margin was melted back. Periodically there seem to have been great oscillations, so notable in their extent and in their effects as to be designated stages of the Pleistocene epoch. During these stages of glaciation the ice advanced far to the south, driving the plants and animals before it, destroying and burying in the drift such as remained, and introducing a fauna and a flora of the higher latitudes. During the stages of deglaciation a reversal of these conditions took place. The climate became so much milder that the ice was melted and a new soil developed, and plants and animals returned to their former habitats. This stage prevailed until the return of arctic conditions brought about a readvance of the ice and the deposition of a new sheet of drift, burying the soil and the organic remains.

Study of these buried soils and organic remains and of the conditions of the several drift sheets has led to the determination that the Glacial epoch comprised a series of these glacial and interglacial stages. The following classification has been made of the deposits formed during these several stages of glaciation and deglaciation of the northern interior of the United States:

Drift sheets and intervening soil horizons of the northern Mississippi region.

11. Late Wisconsin drift sheet.
10. Fifth interval of recession, shown by the shifting of the ice lobes.
9. Early Wisconsin drift sheets.
8. Peorian soil and weathered zone; fourth interval of recession or deglaciation.
7. Iowan drift sheet and main loess deposit.
6. Sangamon soil and weathered zone; third interval of recession or deglaciation.
5. Illinoian drift sheet.
4. Yarmouth soil and weathered zone, and Buchanan gravels; second interval of recession or deglaciation.
3. Kansan drift sheet.
2. Aftonian gravel and soil deposit; first interval of recession or deglaciation.
1. Sub-Aftonian drift sheet.

Of the several drift sheets, it is not certainly known that more than one, a late Wisconsin drift sheet, is represented within the Milwaukee district, though there are good reasons for believing that an earlier glacier of the Wisconsin stage and glaciers of the Illinoian or Iowan stage, or both, crossed the area and left their deposits. The earlier deposits are not very certainly distinguishable. The occurrence of buried vegetal remains has also been reported at one or two places. These may be remnants of some one or more interglacial deposits.

PRE-WISCONSIN DEPOSITS.

The areal distribution of the drift sheets of eastern Wisconsin is shown in fig. 4. From this map it will be seen that eastern Wisconsin is for the most part covered by a drift sheet of Wisconsin age. Beyond the limits of this later drift, in southwestern Walworth County, Rock County, and parts of Dane and Green counties, there is a sheet of drift which bears evidence of having been deposited at an earlier stage of glaciation—just at what stage has not been determined, though certain evidence makes it probable that it was laid down during either the Illinoian or the Iowan stage.

The lithologic composition of this older drift sheet, the bearings of the striations on the rock surfaces, and the trend of certain topographic features of the drift show that the ice which made the deposit was moving in directions varying from southwest to west and probably traversed the whole of the southeastern part of the State, including the Milwaukee district. It is probable that more or less of the drift deposit of the Milwaukee district belongs to the earlier drift sheet. However, so completely is the older drift covered by the drift of the Wisconsin stage that it has been distinguished in but few places with much certainty.

In the lower part of the lake bluff in the towns of Lake and Oak Creek, Milwaukee County, and in the slopes of the Menominee Valley in Milwaukee and Wauwatosa, there are deposits of a brownish or reddish-brown clay which is so dense and hard that one can scarcely dig into it with a pick. At those points along the lake shore where this clay occurs masses of it are rounded by the waves and buried in the Recent sand and gravel. As similar clay balls occur in the beds of sand and gravel overlying the dense clay in the bluff section and also in exposures in the Menominee Valley, it probably was already hard and resistant when the beds were deposited, possibly because it was frozen. The clay generally contains but few stones and is often laminated. It may have been deposited at one of the earlier stages of glaciation and may owe its compactness, in part at least, to its having been overridden by the later glacier. At several places where this clay is interlaminated with fine sand the beds are as greatly crumpled and contorted as are the metamorphic rocks. This crumpling also may be due to the fact that the deposit was overridden by later ice sheets.

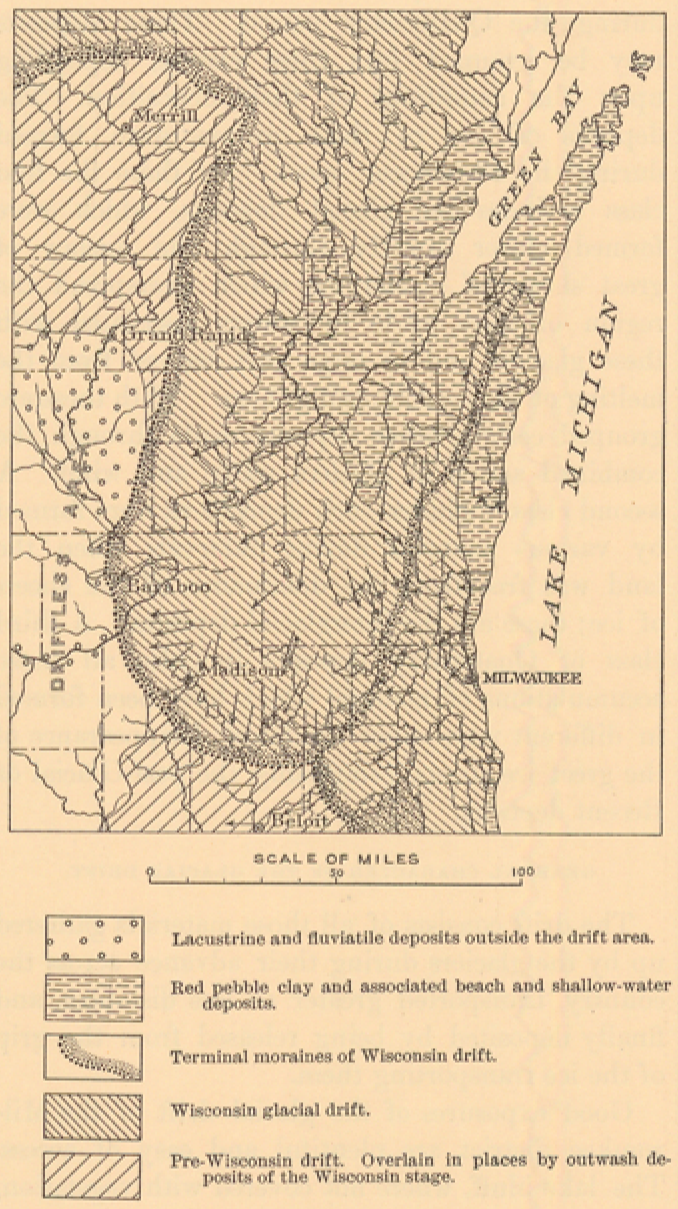


FIG. 4.—General map of the Quaternary formations of eastern Wisconsin.

Data principally from Plate II, Atlas Wisconsin Geological Survey.

Many wells in the area penetrate hard, compact till, popularly known as "hardpan," in the lower part of the drift, beneath a deposit of sand and gravel. It is probable that many if not all these deposits of "hardpan" should be classed with one of the older drift sheets.

INTERGLACIAL DEPOSITS.

Above the dense, brownish, pebbly clay lie variable thicknesses of stratified clays, sand, and gravel, which probably represent a stage when the margin of the glacier depositing the lower till had been melted back to the east, to or beyond the position of the present lake shore. The present conditions indicate that this would result in the ponding of waters between the glacial front and the higher land to the west and in the deposition of stratified material. Some of the best exposures of these stratified beds in the Menominee Valley are at the several brickyards and at Story Brothers' stone quarry. At this stone quarry 50 to 60 feet of stratified material occurs, including dense, finegrained, laminated red and blue clay, sandy clay, cross-bedded sand, and fine and coarse gravels, the coarser material occurring principally in the upper part of the section. At the time of the writer's visit there was a fine exposure of stratified drift on the east side of the valley southeast of Story's quarry, near the corner of Fortieth street and Park Hill avenue. At the bend in the valley and in the bluff north of the Chicago, Milwaukee and St. Paul Railway shops the coarser sand and gravel is in places cemented into a conglomerate, which projects in ledges from the slope. At several exposures some of the laminated clays are contorted, as though subjected to lateral pressure by the overriding of the later ice sheet. The stratified deposits are nearly everywhere overlain by variable thicknesses of buff to bluish till of the late Wisconsin stage.

Doubtless vegetal deposits were generally formed during the intervals of prevalent warmer climate, yet it is not surprising, in view of the later vigorous glaciation, that so few remnants have been noted. In 1889 a boring was made on the crest of the lake bluff east of South Milwaukee, at a point about 105 feet above the lake. At a depth of 114 feet a bed of "dry turf" 6 feet thick was penetrated, beneath which was 7 feet of clay and sand, 12 feet of "hardpan," and a bed of lime rock. About 5 miles west of South Milwaukee, at a depth of 24 feet, a bed of black loam, becoming sandy at the bottom, was penetrated. This bed was said to be 14 feet thick; below it was sand, gravel, and clay. A well on the crest of the ridge about 3 miles northeast of Hales Corners, in the town of Greenfield, encountered a bed of "black sand" at a depth of 26 feet.

These are the only instances of buried vegetal deposits or old soils that have come to the notice of the writer within the Milwaukee area. It is obvious that no correlation can be made of such meager data. The deposits may have belonged to one interval or to different intervals of glaciation.

EARLY WISCONSIN DRIFT.

No deposits of the earlier glacier of the Wisconsin stage of glaciation have been distinguished in the Milwaukee district, though the disposition of the terminal moraines in northeastern Illinois makes it probable that this district was subjected to glaciation during the earlier part of the Wisconsin stage.

LATE WISCONSIN DRIFT.

The ground moraine.—The ground moraine is the accumulation of débris formed beneath the ice during the progress of its advance. The deposits constituting the ground moraine are in many places covered to a greater or less extent by accumulations of drift formed at the margin of the glacier during the melting of the ice sheets or during stages of halt or readvance which interrupted the general process of deglaciation. Such deposits, though not always greatly different from those formed during the advance, are more apt to be concentrated in ridges or belts, and should be distinguished from the ground moraine proper. This is especially true in the Milwaukee district, where the areas that were not modified more or less by the deposition of drift during these interruptions of the process of final deglaciation were comparatively small. These limited areas within this district which might still be considered as ground-moraine tracts are the drift areas that intervene between the morainal ridges shown on the map, and even here the drift is largely covered by the humus deposits of post-Glacial time. In these gently undulating tracts, so far as can be determined from the exposures and from the records of wells, the deposit is till of the ordinary type. The characteristic features of the ground moraine are better developed in the area just west of the limits of the Milwaukee quadrangle than in these scattered areas within the district.

Terminal moraines.—Whenever the glacier reached such an extension that the rate of melting in the marginal parts of the ice sheet equaled the rate of advance the ice front halted and the continued deposition at the margin formed a more or less ridge-like accumulation of drift—that is, a terminal moraine. It is probable that this zone of deposition often extended back under the thinned marginal parts of the ice sheet some distance from the actual front of the glacier. The morainal dump of drift piled upon and against the actual margin of the ice was subjected to more or less crowding and heaping by the mechanical push of the glacier when slight advances occurred. This developed rougher ridging and sharper contours than are seen in those submarginal moraines formed by the mere lodgment of the drift. The ice action in the latter case is thought to have been of the nature of overriding or oversliding, rather than of pushing or plowing, and consequently the contours are of a billowy type. These lodge moraines are from a mile to several miles in width.

Such terminal moraines were formed both at the limits of the glacial advance and also at places where the margin halted at intervals during the general process of final deglaciation of the area. Terminal moraines of the latter class have been referred to by some authors as moraines of recession. To this class belong those terminal morainal belts bordering Lake Michigan in this and adjacent parts of southeastern Wisconsin.

Lake-border morainic system.—In his studies of the drift of Illinois (Bull. No. 2, Chicago Acad. Sci., 1887, pp. 42–47; Mon. U. S. Geol. Survey, vol. 38, 1899, pp. 380–412) Mr. Frank Leverett found a system of ridges continuing southward from the Wisconsin line into Cook County, Ill., between the Valparaiso moraine and the lake shore. The northward continuations of the ridges in Wisconsin are shown in fig. 5. While in a large part of

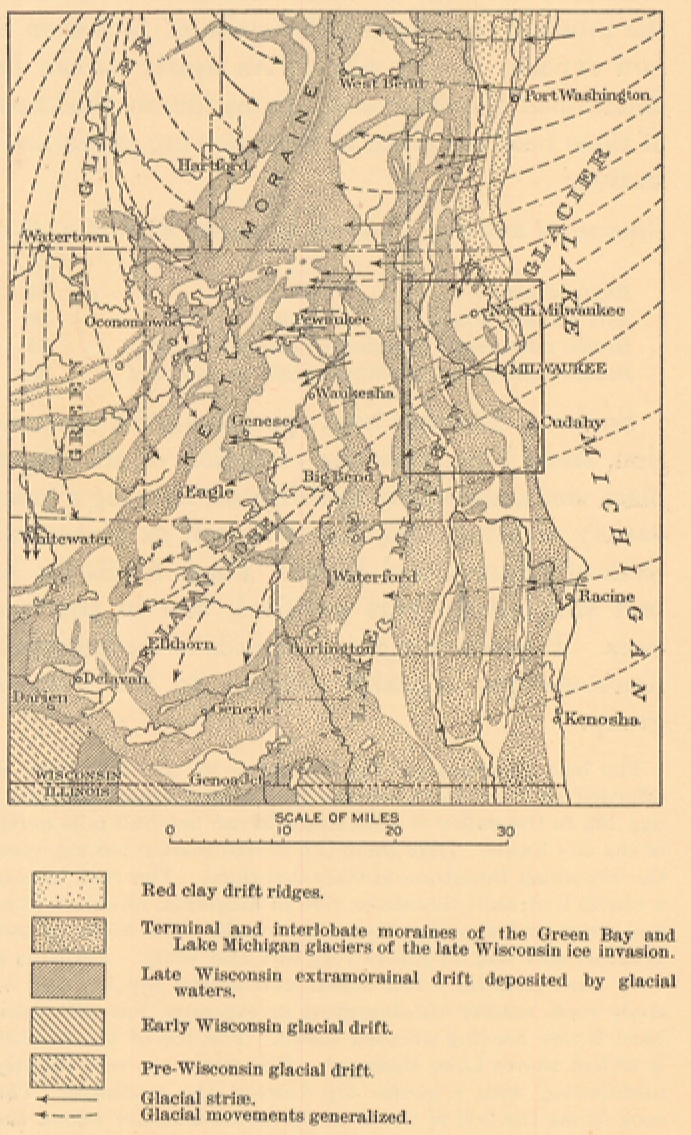


FIG. 5.—Map of the Glacial deposits of southeastern Wisconsin.

Area of the Milwaukee special quadrangle is indicated by heavy rectangle.

this extent the ridges are clearly marked and distinctly separated so as to give the peculiar trend to the drainage lines already noted, they are cut through in some places by the streams and in some places contiguous ridges are coalescent, so there may be some difference of opinion as to the exact correlation here given. This is, however, of little moment as long as the distinctive features of the area are recognized.

The general topography of the lake-border ridges shows gently flowing contours, as of drift overridden by the ice, whence they appear to be of the lodge-moraine type. Here and there groups of kettle holes pit the surface, and at some places considerable deposits of gravel occur. Surface bowlders are very abundant in parts of Greenfield and Franklin townships. They were formerly much more abundant on the ridges nearer the lake, but a large part of them have been collected and used in the construction of piers, breakwaters, and other structures.

The first and westernmost of the ridges is that just west of the continuous valley which is occupied in part by Underwood Creek and in part by Root River. It varies in width from 1 to 4 miles, and its crest, which here marks the position of the continental divide between the waters of the St. Lawrence and the Mississippi river systems, stands 220 to 360 feet above Lake Michigan. On the west the slope rises 20 to 60 feet above the adjacent marsh and ground-moraine tracts; on the east it drops down 100 to 150 feet to the adjacent valley bottom.

The thickness of the drift in the part of the ridge lying within the area ranges from a few feet, where the rock elevation at the Trimbone quarry is crossed, to nearly 200 feet. A part of the drift was probably deposited during the earlier ice advance, yet no definite horizon separates the earlier from the later drift.

The great bulk of the material composing this ridge and also the ridges to the east is a moderately stony calcareous till of a bluish color. The upper part of the till is generally oxidized to a buff color. The depth to which it is leached of its calcareous material varies from 1 to 3 feet. At a few places in the town of Brookfield, Waukesha County, the subsoil is brownish and putty-like in consistency. At some places it has a pinkish tint and at others it has a purplish-red color. At many exposures the till is very stony, but in general the amount of stony material it contains is notably less than that in the drift of the areas to the west. In places the clay near the surface is almost stoneless, but the stones which are generally of small size and well glaciated, increase in number downward. Bowlders a foot or more in diameter are not plentiful. Most of the wells along this ridge penetrate more or less sand and gravel. Probably more than one-half draw their water from such deposits; many, however, show but a few feet of sand and gravel. Gravel deposits are not plentiful at the surface.

A group of small gravel knolls or kames of 10 to 30 feet relief occurs 2 miles west of the village of North Greenfield, just south of the Chicago and Northwestern Railway. These gravels continue one-half mile southward as a terrace along the lower east slope of the ridge. A few gravel knolls with 20 to 40 feet relief occur at Hales Corners and a single kame lies 2 miles west.

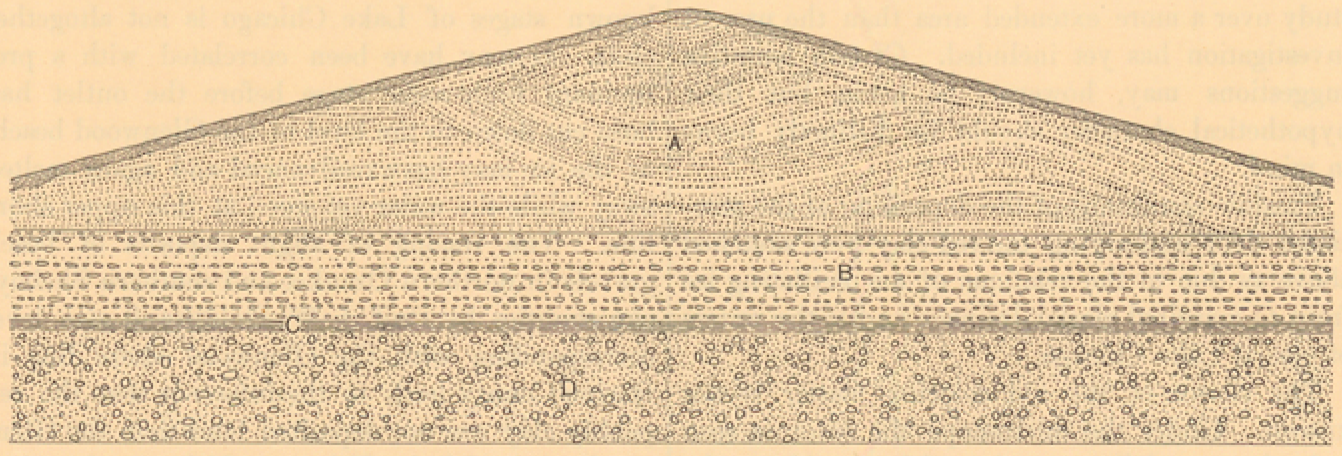


FIG. 6.—Section of kame at William Cobb's gravel pit, Hales Corners.

A, irregularly stratified gravel covered by soil; pebbles mostly less than 3 inches in diameter; B, horizontally bedded, coarse gravel with sharply marked upper limit; C, finely laminated sandy clay; D, unassorted coarse gravel and cobblestones. Height of section, 38 feet.

William Cobb's gravel pit at Hales Corners gives an excellent section of a kame composed entirely of stratified material. The kame is somewhat elongated in a northeast and southwest direction—that is, transverse to the trend of the morainic belt. The section shown in fig. 6 is transverse to the main axis and is concave to the southwest. The height of the section is 38 feet. At the bottom are 8 feet of coarse gravel and cobblestones (D), stained yellow, brown, and black, and showing no assortment. Upon this lies a stratum (C), 1 foot thick, of finely laminated clay, nearly horizontal and continuous across the section. Above these laminated clays are 12 feet of horizontally bedded coarse gravels (B). The line marking the top of the gravels is horizontal and very distinct across the section. The upper 17 feet (A) are of gravel, with pebbles mostly smaller than 3 inches in diameter and beautifully bedded in undulating lines. The significant feature of this section is the undisturbed condition of its gravels. This may be evidence that the ridge was not again overridden by the ice; also that the deposits must have been formed in situ and could not have been let down from a higher horizon by the melting of the surrounding ice. This section, however, is not to be taken as typical of the kames of southeastern Wisconsin. Most of the kames seen by the writer are composed of unassorted cobblestones and gravel.

The kettle holes are usually small and but 5 to 15 feet deep, shaped much like saucers or shallow bowls. Two miles southeast of Hales Corners is a small area where the kettles are about as thickly set as possible.

The bowlders are most abundant near Hales Corners. In some places it would be quite possible to walk several rods by stepping from one stone to another. These bowlders range from 1 to 3 feet in diameter and are generally well rounded. They rarely show facets and striations such as are commonly seen on the stones in the body of the drift. Fully 95 per cent of them are fragments of crystalline rocks of the more basic varieties, in which ferruginous minerals abound. The ready oxidation of these minerals causes the surfaces of the bowlders to disintegrate and produces rounded forms. Since these bowlders occur so largely on the surface and in comparatively small numbers in the body of the drift, and since they are so largely composed of foreign rock and have traveled so far, it seems probable that they represent the englacial drift. If they were carried well up in the body of the drift they would not have been so much abraded as was the basal material.

East of the valley occupied by Root River and Underwood Creek is a broad belt with topography like that of the west ridge, but in southern Milwaukee County this belt is marked by two more or less distinct crests. In the town of Greenfield it shifts to the northwest, and in the town of Wauwatosa this shift is even more pronounced, so that the narrowed northward continuation of the ridge lies west of Menominee River. The surface of this tract is in general mildly undulating, but in the town of Greenfield, Milwaukee County, and at several places farther south, sags and short undulations, kettle holes, and foreign bowlders abound. The thickness of the drift ranges from 20 to 200 feet. In parts of southeastern Wauwatosa Township a loose sandy or sandy-clay soil rests upon the clay subsoil. At numerous places on the west crest and very generally over the east crest in the towns of Greenfield, Lake, Oak Creek, and in eastern Franklin there is a reddish-clay subsoil, much resembling the red clay of the lake bluff. Where this clay is exposed at the surface the reddish color has been more or less washed out of the surficial part and the soil has a grayish cast. Thicknesses of reddish clay ranging from a few inches to 17 feet are reported. Farther west the reddish color gives place to a light buff.

Near Calvary Cemetery, west of Milwaukee, considerable deposits of gravel in kame-like accumulations have been removed. These deposits are much like those at Wauwatosa, north of the river, with which, indeed, they were probably once continuous.

The most strongly marked of the morainal ridges in the area extending from Milwaukee southward is that nearest the lake shore. From Cudahy southward it has a north-south trend, nearly parallel to the lake shore. North of this place it makes a shift to the northwest, indicating a distinct lobation of the west margin of the ice sheet at the time of its formation. Its northward continuation appears to be the ridge lying east of Menominee River and extending from Wauwatosa northward. The crest of the east ridge ranges in elevation from 120 to 200 feet above the lake. This is in general about 40 to 60 feet lower than the higher crest of the middle belt and 100 to 160 feet lower than the crest of the west ridge.

Through nearly half of the southern 60 miles of its extent in Wisconsin the bottom of the valley to the west is a marshy flat, poorly drained, whence it is evident that the separation of the ridges is not due to post-Glacial erosion. In the parts traversed by streams more or less erosion has been accomplished, but this has been confined to the deepening of the original valley. In general the eastern slope of the ridge is longer and less abrupt than the western, but through the southern part of the towns of Lake and Oak Creek the eastern slope has been partly cut away by the encroachment of the lake, forming a bluff rising 100 to 160 feet above the water's edge.

A notable deposit of gravel extends from a point 1 mile east of Wauwatosa southeastward to the lake shore northeast of Cudahy. At Wauwatosa the deposit has been very largely excavated, but when visited by the writer a few kame-like accumulations still remained, though they were being removed. In some places the gravel was not merely superficial accumulation, but extended down into the body of the ridge. A well in the western part of Wauwatosa extends to a depth of 64 feet in sand and gravel, and at other points 10 to 50 feet of assorted material is exposed. Much of the gravel is fine, clean, well waterworn, and beautifully bedded, showing considerable water action in connection with the ice.

From the bend in the Menominee Valley east of the Soldiers' Home southeastward to the lake the gravels are nearly continuous, the deposit being marked by kettle holes and marshy depressions near Forest Home Cemetery. From Howell avenue eastward to the lake they constitute a mild type of kettle moraine. From Kinnickinnick River southeastward the gravel belt lies just northeast of the main till ridge. In places there is a distinct valley between, but north of Cudahy the surface undulations are continuous with the till ridges, so that the two appear to be closely related. The assorted drift was probably deposited by a marginal glacial stream flowing inside the main ridge of the moraine, from which the ice front had withdrawn a short distance. A similar belt of gravels borders the lower course of Oak Creek on the north.

The records of wells in the east ridge show that it is generally made up of less sand and gravel and more moderately stony till than is seen in the exposures in the vicinity of Milwaukee and Wauwatosa. At many places in Milwaukee County, especially in Lake and Oak Creek townships, the upper part of the till, beneath a few inches of soil, is reddish to reddish brown in color. This bed usually grades downward into bluish till within a few feet, but some wells, as reported, have penetrated 15 to 18 feet of reddish clay before reaching the blue clay. In general, however, the upper 5 to 15 feet are of light-buff color, grading into bluish below. In some places the soil is loose, slightly sandy loam.

The lake bluff in southern Lake and Oak Creek townships and for a mile or more in Racine County gives a section 60 to 160 feet in height of the drift composing this ridge. Probably not all of the drift here exposed was deposited during the stage of final melting of the ice; a considerable part may have been deposited during the advance of the ice; yet the deposits of the advance and of the retreat can not be very clearly distinguished. It is also probable that the exceedingly hard brown and reddish-brown clay in the lower part of the bluff section was the deposit of an earlier advance of the ice and was overridden during the later advance.

The drift in the lake bluff from a point 1 mile northeast of Cudahy southward for nearly 10 miles exhibits great variation in structure and composition (fig. 7, A and B). The bluff at Bayview and

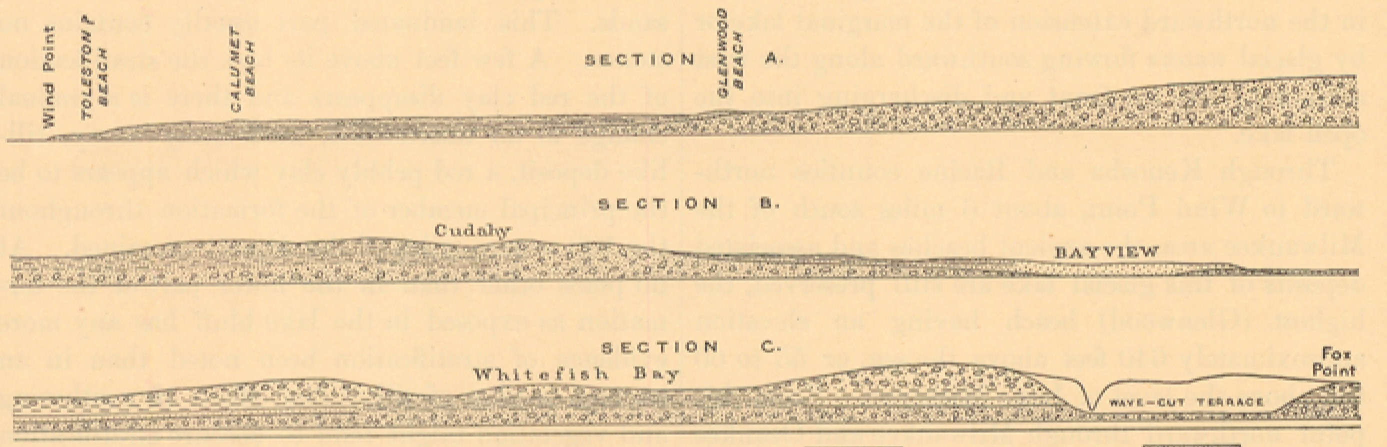


FIG. 7.—Sections exposed in the lake bluff in the Milwaukee Special quadrangle and vicinity. Horizontal scale, 1 inch = 1 mile; vertical scale, 1 inch = 500 feet.

Section A. From Wind Point, near Racine, northward into Milwaukee County. Beach deposits and red clay of the Glenwood stage of Lake Chicago.
Section B. From the vicinity of Oak Creek northward to the Bayview Steel Mills, showing beach deposits, possibly of the Glenwood stage.
Section C. From Lake Park northward to Fox Point. Red till and laminated clay overlying stratified sand and till.

at points farther south shows a fine series of lacustrine deposits, which are discussed under the heading "Lacustrine phenomena," on page 7. More or less till occupies the lower part of this section, and as the moraine under discussion is approached the till rises in the section until at the point where the moraine is cut through by the bluff the full section is of buff and blue stony till. This unstratified section is, however, but one-half mile in extent. South of this, to the mouth of Oak Creek, a distance of $3\frac{1}{2}$ miles, a large part of the bluff section is composed of stratified material—sand, gravel, and clay. South of Oak Creek the bluff is mostly till, buff above and bluish below; in places the blue grades downward into very hard brownish till.

The observed thicknesses of drift in the east ridge range from 25 feet to more than 200 feet. As in the other ridges of this system, the thickness is in general greater from the southern part of Milwaukee County southward. The stratified drift of the lake-bluff section and that of the Menominee Valley indicates very considerable water work in connection with the ice.

South of the intersection of the moraine by the lake bluff northeast of Cudahy no further morainal deposits are found, owing to the encroachments of the lake, but north of this point the ridges shift westward and later deposits remain. Traces of a later moraine are seen in two ridges west of Milwaukee River. One extends about $2\frac{1}{2}$ miles in a direction north-northwest from Reservoir Park, through the Thirteenth and Twenty-first wards. The other extends $2\frac{1}{2}$ miles in a direction slightly east of north from a point $1\frac{3}{4}$ miles north of the railway junction at North Milwaukee. The latter ridge carries abundant crystalline bowlders upon its surface, some of which are of large size. One mile west of this ridge is another elevated tract. Some slight morainic features occur also in the vicinity of South Park, in the Seventeenth Ward.

The drift between the east ridge and Milwaukee River north of Menominee River and between this moraine and the lake south of this stream shows about the same variety in composition and structure as that in the belt just described. Reddish clay occurs in many exposures and stratified drift is abundantly present with the unstratified. The known thickness of drift in this tract ranges from 35 to 200 feet.

Assorted drift deposits overlying the blue bowlder clay and underlying the red bowlder clay.—From the vicinity of Cudahy northward the lake-bluff section exposes considerable deposits of assorted drift overlying the blue bowlder clay of the main drift sheet and, north of Milwaukee, underlying a deposit of red pebbly clay. The relations of these deposits are shown in fig. 7, B and C. The assorted deposits, which range in thickness up to 30 or 40 feet, consist chiefly of sand and gravel. Interstratified with the sand are layers of very fine sand, buff sandy clay, and laminated red and blue clay. As traced laterally the formation may show a uniform character for some distance or it may exhibit rapid changes in structure and material. At one point it may consist almost wholly of fine sands and clays and a few rods distant these may give place to coarse sand and cobblestone gravel. The deposits are nearly everywhere beautifully stratified, the finer material being commonly disposed in delicately wavy lines, while sags and cross-bedding mark that which is coarser. At many places the exposure of these assorted deposits is obscured by slumping of the overlying material, and at some places the stratified beds thin out and disappear, so that the stony red clay above grades imperceptibly into the stony bluish till below, but generally the assorted drift may be traced continuously in the bluff face.

In order to ascertain, if possible, how far these stratified sands and gravels extend westward beneath the red clay which overlies them in the bluff section, a correlation was made of such data as were secured from the records of wells scattered over the red-clay area in Milwaukee and Ozaukee counties. Of the 122 wells concerning which definite information was obtained, 24 show deposits of sand and gravel between the red clay and the blue till. In 68 wells the red clay immediately overlies the blue till, with no intervening sand or gravel. Twenty-three wells show sand and gravel below varying thicknesses of clay, but it could not be determined whether the clay included both red and blue clay or only red. Seven wells reached the bed rock without penetrating either sand or gravel. From this it is seen that while a possible 47 out of 122 wells might be taken as affording evidence of the westward extension of this formation, the remaining 75 wells give positive evidence to the contrary. Certain exposures near Mineral Spring Park, in the north part of Milwaukee, show the red clay overlying the blue till with no intervening sand or gravel. To this should be added the testimony of several well drillers who have worked extensively in the area between Milwaukee River and the lake. These concur in saying that although local deposits of sand and gravel are frequently encountered in the blue till, yet the till is usually immediately overlain by red clay without such intervening deposits.

Although information was not obtained concerning all of the wells and the data procured are not uniformly accurate, yet there seems to be little question that the associated drift has not the considerable westward extension which its exposure in the bluff section seems to imply. The best evidence of such an extension seems to be found in the area immediately west of Whitefish Bay. Here the deposit of red clay has been narrowed in places to a width of less than 100 rods. Several wells show the presence of sand and gravel below 10 to 40 feet of red clay, and immediately west, bordering the river, is an extensive deposit of sand and gravel, which may possibly be the continuation of the beds exposed in the bluff section. As is noted under the heading "Outwash deposits," the writer is inclined to regard the sand and gravel along the river as an outwash deposit formed by glacial drainage during glacial deposition of the red clay, a continuation of like deposits bordering the stream farther north.

Relations of these assorted deposits to the deposits of glacial Lake Chicago.—The exact conditions under which these assorted deposits were laid down are somewhat open to question. The fact that they overlie the blue till which constitutes the main drift sheet of the region indicates that the ice front had been melted back from the lake-border moraines, at least as far north as Sheboygan County, when they were deposited, so that the deposition of the till was succeeded by aqueous deposition. Studies in areas lying farther south have shown that the withdrawal of the glacial margins within the lake basin resulted in the flooding of the basin by the waters of a lake, glacial Lake Chicago, which discharged through an outlet southwest of Chicago, and it seems probable that the assorted drift under discussion was deposited either in the northward extension of the marginal lake or by glacial waters flowing southward along the west margin of the ice front and discharging into the open lake.

Through Kenosha and Racine counties northward to Wind Point, about 6 miles south of the Milwaukee area, the ancient beaches and associated deposits of this glacial lake are still preserved, the highest (Glenwood) beach having an elevation approximately 640 feet above the sea, or 55 to 60 feet above the level of Lake Michigan. From this point northward through Milwaukee and Ozaukee counties no traces of the upper ancient beaches remain to show the exact relations of the lake to these assorted deposits.

The stratified beds exposed in the bluff reach an average elevation of about 55 feet above the present beach, so that in large measure they correspond in elevation with the Glenwood stage of Lake Chicago. At numerous places, however, these deposits rise 70 to 80 feet above the present water level, which is higher than any definitely marked level of the lake about the south end of the basin, so that some special conditions must have been afforded for their deposition. These may have been furnished by the relations of the lake to the marginal drainage along an oscillating ice front. It is not necessary to suppose that the ice had entirely disappeared from the vicinity of Milwaukee so as to leave an open lake at or near whose shore the stratified beds were laid down. It is not improbable that the ice front was near by, oscillating back and forth under varying conditions of melting and advance. At times an increase of wastage may have allowed extension of the lake northward, with consequent deposition of finely interlaminated sands and silts; again, the expanding glacier may have crowded upon the land nearly as far south as Cudahy, contracting the lake to a lagoon and finally to a marginal stream. To such a stream, shifting back and forth upon the land with the oscillations of the ice front, may have been due the deposition of some of this stratified material, especially the higher level sands and gravel. Such an alternation of glacial, lacustrine, and fluvial conditions would agree very well with the variable character of the stratified beds observed.

Laminated red clay and red pebbly clay.—Upon the stratified sands and gravels exposed in the lake bluff from Milwaukee northward lies a deposit of red clay, the exact time and mode of whose deposition is also somewhat in doubt. So small a part of the deposit lies within the bounds of the Milwaukee district that the present discussion is based upon observations made throughout all that part of the red-clay area which has been examined by the writer, about 100 square miles, principally in Milwaukee and Ozaukee counties.

The deposit consists of a dense marly clay, varying in color from light terra-cotta red to brownish or purplish red, which on long exposure weathers to an ashen-drab tint. The color of the clay is very noticeable, giving a decidedly red color to roads, excavations, and freshly plowed fields within its area. In some places near the western margin of its area its color becomes more brownish or yellowish, so as to be less easily distinguished from the weathered part of the bluish till.

The bulk of the red clay is of fine grain, in some places almost putty-like. Microscopic examination shows a considerable amount of finely comminuted quartz and other material intermingled with the aluminous particles, so that while the whole is compact, impervious, and very hard when dry it has not the extreme tenacity of the typical aluminous clays. One ingredient is magnetite. This is the source of much of the black sand seen on the beach. A small portion of the grains of the various minerals are rounded, but the greater number are angular and fragmental. This clay does not crumble loosely when it breaks down, but falls into little angular blocks one-fourth to one-half inch in diameter.

There are two more or less distinct divisions of the red clay. The lower portion, which in the bluff section immediately overlies the stratified sands and gravels discussed above, is usually beautifully laminated, indicating deposition in still water. On one point on the shore of Whitefish Bay the lower laminæ undulate over undisturbed ripple marks at the top of the stratified sands. This laminated part usually contains no stones. A few feet above its base the stratification of the red clay disappears and there is a gradual change to an unstratified, moderately stony, till-like deposit, a red pebbly clay which appears to be the principal member of the formation throughout the 100 square miles of the deposit examined. At no place other than in the lower part of the formation as exposed in the lake bluff has any more evidence of stratification been noted than in an average section of till. The effects of weathering and vegetation might tend to obscure stratification within a few feet of the surface, but many of the exposures seen extend well below this zone. In places the stony material is abundant, but it is generally much less so than in the blue till exposed at the bottom of the bluff and in other parts of the area. The pebbles are usually rather small, but occasional small bowlders are seen. The stones are similar to those of the blue bowlder clay in their variety of lithological characters and angular to subangular shapes, and in showing glacial facets and striations. In other words, the red pebbly clay appears to be glacial till somewhat different in character from the bluish till previously deposited. Here and there crystalline bowlders are scattered over the surface of the red bowlder clay. At some places they are numerous, but over most of the area they are rare. Throughout Ozaukee County this scarcity of bowlders is in striking contrast with their abundance in the morainal belts to the west; in Milwaukee County the contrast is not so great.

The combined thickness of the red pebbly clay and the laminated red clay varies considerably; in the bluff section the variation is from 1 to 80 feet. So far as has been learned from the correlation of data from wells scattered over the red-clay area, the variations in general are greater than in the bluff exposure. The average thickness penetrated by these wells is about 25 feet; that of the bluff section is about 40 feet.

The red pebbly clay is generally disposed in a series of broad, gently sloping parallel ridges resembling in form and distribution the ridges of the lake-border morainic system described above. These ridges of the red-clay area have the characteristics of till billows, with the eastern slopes longer than the western. The height of the eastern slopes is 40 to 80 feet; of the western 20 to 40 feet. Where erosion has deepened the troughs between the ridges the relief is of course greater. Except where so modified the troughs are of a depositional type, the sharp cutting of the streams being usually clearly in contrast with the original slopes. The shore of the lake in its present position cuts obliquely across the trend of these ridges, so that the height of the bluff and the thickness of the deposit of red clay there exposed varies with its relation to the ridges and the intervening troughs. This fact is shown very clearly where the reentrant shore of Whitefish Bay has cut nearly through the west ridge (fig. 7, C), the only one extending southward into Milwaukee County. The crest of this ridge within the Milwaukee district stands 120 to 140 feet above Lake Michigan. Farther north, in Ozaukee County, the crest of this ridge, which is the highest of the series, stands 240 to 300 feet above the lake.

As previously indicated, the conditions under which the red pebbly clay and the underlying laminated red clay were deposited are still somewhat open to question. The problem requires study over a more extended area than the present investigation has yet included. Certain tentative suggestions may, however, be made, but their hypothetical character should be distinctly borne in mind.

Possible conditions of the deposition of the associated drift underlying the red clay were sketched above as due to the relations of an oscillating ice front to marginal glacial drainage and to the waters of glacial Lake Chicago.

The source of the red coloring matter is not known. Under the microscope the color is seen to be due to a delicate coating of iron oxide on the grains of the various minerals. The color is not such as results from weathering in this climate and moreover it is impossible to suppose that so thorough oxidation of so dense and impervious a clay could have occurred since its deposition. The clay was evidently derived from red beds or coloring matter was introduced into it during its deposition. Comparatively little red material is included in the deposits previously laid down in this area, so that some new ingredient appears to have been introduced into this deposit. It is suggested that coloring matter from the red beds of the Lake Superior basin, such as characterizes some of the deposits of the Lake Superior glacier, may have been introduced into the Lake Michigan basin by marginal glacial waters coming from the upper lake basin. This coloring matter might be thoroughly commingled with drift being deposited in the lake from the front of the contracted glacier.

These deposits dropped in the lake basin would probably be in large part in the form of till. Some of the material may have been dropped as berg till by ice floating out from the glacier. Some of it would be assorted and laminated by the lake waters. Such parts of the area north of Milwaukee as had sufficiently low elevation would be submerged by the waters of Lake Chicago, and over such submerged tracts laminated clays and berg till would be laid down. Whether or not differential northward depression was associated with these closing stages of glaciation in this region is not known. So far as the present study has proceeded, no indications of such depression have been noted. If, however, it occurred, by so much would the waters of the marginal glacial lake have transgressed on the area that is now land and have extended the lacustrine and glacio-lacustrine deposits.

For the distribution of the red pebbly clay over the stratified deposits it seems necessary to postulate a readvance of the glacier southward to the vicinity of Milwaukee and its crowding laterally upon the land approximately to the present line of Milwaukee River. Such a glacial readvance would probably have carried up from the lake bottom considerable red clay and deposited it upon the stratified deposits; or, if the glacier was previously carrying red drift its deposition would be continued upon the area that is now land.

In the conditions afforded by the final melting of the glacier from this area by stages is found an explanation of the gentle parallel ridging of the red pebbly clay similar to that noted in the drift ridges of the lake-border morainic system previously described.

A study of the United States Lake Survey charts has brought out the fact that the part of the lake basin between Milwaukee, Wis., and Grand Haven, Mich., is much shallower than that between Racine, Wis., and Holland, Mich. East of Milwaukee the lake bottom is nowhere less than 200 feet above sea level, while opposite Racine the bottom reaches sea level. This line between Milwaukee and Grand Haven seems to mark nearly the summit of the ridge between the two basins, both of which, with the dividing ridge, are covered by the lake. Although its position and origin are unknown, the ridge may consist, in part at least, of morainal deposits of one of the later stages of glaciation, and possibly it may mark the limit of the readvance of the glacier at this stage. It seems necessary to postulate some such combination of fluvial, lacustrine, and glacial conditions in order to explain the character and distribution of the red pebbly clay and associated stratified deposits. The exact relation of this supposed readvance of the glacier to the known stages of Lake Chicago is not altogether clear. It may have been correlated with a preliminary high-water stage before the outlet had been cut down to the level of the Glenwood beach, or the ice may have readvanced and again melted away while the water yet stood at this upper shore line. The tracing of slight deposits of beach gravels in northern Ozaukee and southern Sheboygan counties by Prof. J. W. Goldthwait at a level corresponding with the Glenwood shore line in Racine County leads to the inference that the red pebbly clay was not deposited later than the Glenwood stage of Lake Chicago. If it was deposited at this stage the lake was extended northward as the ice front finally retreated and slight beach deposits were then developed upon the red pebbly clay.

A somewhat different interpretation was placed upon the deposition of the red clays and associated assorted deposits by Professor Chamberlin in his earlier studies, as presented in Geology of Wisconsin, vol. 1, pages 292 to 295, and vol. 2, pages 219 to 233. As a result of those studies a readvance of the glacier was not definitely postulated, but a differential northward depression was supposed to have taken place to a degree sufficient to permit the deposition of the stratified sands and gravels as a beach deposit and of the overlying laminated red clay and red pebbly clay as an offshore deposit.

Certain points which favor the alternative hypothesis of combined glacial, fluvial, and glacio-lacustrine deposition of these beds presented above may be cited very briefly. Without postulating a considerable northward depression or local warping of the surface this hypothesis accounts for the decided till-like character of the larger part of the deposit and explains the occurrence of the red pebbly clay at elevations higher than those of considerable areas immediately to the west, from which such deposits are absent and from which, clearly, they have not been removed by erosion. In this connection it may be noted that the broad, open valley west of the red-clay area occupied by Milwaukee River throughout most of its course between Fredonia and Milwaukee is of a depositional character and is not, as a whole, due to stream erosion. That part which has been eroded is at most places easily distinguishable.

Further, this hypothesis accounts for the total absence of shore phenomena from the west margin of the deposit, so far as observed by the writer. It explains the limited extension of the assorted sands and gravels beneath the red clay by supposing the glacier to have carried the clay farther west than the lake waters extended or than the shifting streams of glacial waters flowed. Finally, it accounts for the gentle parallel-ridged topography developed and the consequent later disposition of the drainage lines.

One of the greatest objections to the explanation of the red pebbly clay here presented is the fact that, so far as noted, the bluff section shows no definite horizon between the laminated deposits and those of the supposed glacier. On the contrary, though the red clay is massive and till-like above, it is often finely laminated below and shows no distinct dividing line between the two parts. It seems paradoxical to maintain that the glacier could override the unconsolidated lacustrine deposits without disturbing the clearly marked stratification or the delicate lamination, when during the previous advance the ice grooved, scored, and polished the solid rock and possibly contorted the laminated beds of the dense brown hardpan; yet difference in conditions may have permitted this very thing to be done. That a glacier can override unconsolidated stratified deposits without seriously disturbing them appears to be shown by the studies of numerous experienced observers. It is not so clear, however, that a glacier could retreat from overridden laminated clays and leave upon them a deposit not sharply distinguished from the undisturbed beds, even though the glacial deposits were of essentially the same materials as the laminated beds. It is possible, nevertheless, that where the overridden surface sloped toward the ice front the conditions furnished by the water ponded along the margin and by the ice floating in these waters and scattering coarse and fine débris might be such as to produce the deposits that are seen here.

Outwash deposits.—A deposit, principally of sand and gravel, which appears to have been formed by the glacial drainage at a late stage of the glacial occupation of the area borders Milwaukee River in the northern part of the Milwaukee district. This is a continuation of like deposits farther north in the same valley. Probably it was formed by the glacial waters escaping while the ice front stood at the west ridge of the red-clay area. In most of the excavations the material is gravel, coarse below and finer above, with the bedding dipping southward as in an alluvial deposit. One exposure near the bridge about 2 miles northwest of Whitefish Bay station shows 15 feet of gravels over 10 feet of red clay.

Lacustrine phenomena.—The relations of the deposits above described to those of Lake Chicago are not so clearly marked as might be desired. Throughout most of their extent in the vicinity of Milwaukee, owing to the encroachment of the lake upon the land, the ancient shore lines and associated deposits have been cut away. Most of the assorted and beautifully stratified sands, gravels, and clays exposed in the bluff from the steel mills at Bayview southward to the intersection of the lake shore with the east ridge of the lake-border morainic system (fig. 7, B) are provisionally referred to the Glenwood stage of Lake Chicago. These include a 20-foot bed of red clay underlain and overlain by sand and gravel. This may be the continuation of the main deposit of red clay north of the harbor, or it may be a secondary deposit derived from this clay. In the vicinity of Wind Point, 15 miles south of Bayview, there is a similar deposit of laminated red clay, with beach sands above and below, which was unquestionably deposited in the waters of the Glenwood stage. South of Racine the red color gradually disappears from the lacustrine deposits, showing that the red material failed to reach that point.

Along the north shore of Whitefish Bay there is a cliff and wave-cut terrace that was formed at a later stage of the lake (see figs. 7, C and 11). This terrace, which lies partly within the bounds of the Milwaukee district and is continuous for 2½ miles northward to and beyond Fox Point, has escaped the complete destruction which other features have suffered. Its width varies from 10 to 40 rods. From a level of a few feet above the present beach it rises gradually westward to the foot of the bluff, where it has an elevation of about 15 feet above the lake.

Lithological character of the drift.—The general statements in regard to the composition of the drift of this region may be supplemented here by a more specific statement as to its lithological composition. No careful analysis of the finer materials of the drift has been made, but at several places the coarser stony material has been somewhat carefully examined. The lake bluff at many places and some other exposures in the towns of Milwaukee, Granville, Wauwatosa, and Greenfield show fragments of limestone, blue shale, and black shale derived from Devonian deposits, and two sections noted show thinly laminated rock closely resembling that at the Mud Creek exposures.

At several places estimates of the percentages of local and foreign rocks in the stony material of the drift were made by actual enumeration. In making the estimates several hundred stones were counted out indiscriminately from various parts of the deposit. These were sorted and the various percentages were noted. Estimates at seven localities within the area here described gave percentages of foreign and local rock material as follows:

Percentages of foreign and local rock material in the drift.

	Foreign.	Local.
East of Forest Home Cemetery, Milwaukee	17.40	82.60
One mile east of Elm Grove	14.00	86.00
One-half mile west of Elm Grove	12.66	87.34
Hales Corners	15.83	84.17
Two miles west of Hales Corners	7.04	92.96
One-half mile northeast of St. Martins	7.00	93.00
One-half mile northwest of St. Martins	15.26	84.74
Average of 4200 specimens	12.74	87.26

A comparison of these estimates with estimates made at 28 other localities in Waukesha, Racine, and Kenosha counties shows that the average result is remarkably near the average for 15,900 specimens examined from these counties. At these 28 localities 14.44 per cent of the rock material examined was of foreign derivation, while nearly all the remaining 85.56 per cent was Niagara limestone. On combining these estimates with those made for the vicinity of Milwaukee it is seen that of the total of 20,100 specimens examined 14.10 per cent were of crystalline rocks, with a very small percentage of sandstones and quartzites, all foreign to the southeastern part of Wisconsin, so far as known, while 85.90 per cent may have been derived from formations present in this area.

If, now, the lithological character of the body of the drift as shown by these estimates be compared with that of the surface bowlders, the contrast is surprising. Although no exact estimates of the percentages of surface bowlders of foreign and local origin have been made, a careful observation of the character and distribution of these bowlders indicates that at least 95 per cent of them are of crystalline rock, with here and there a block of sandstone or quartzite, while the remainder are Niagara limestone.

It will be noted that these facts are directly in accord with the theory that the surface bowlders are for the most part a deposit of englacial drift, and that they were brought to their present locations well up in the body of the ice, while the greater part of the till was basal or subglacial, and was carried but comparatively short distances from the places of derivation.

RECENT DEPOSITS.

Beach sands and gravels.—The principal lacustrine work in the vicinity of Milwaukee since the final disappearance of the glacier from the lake basin, the consequent opening of the straits of Mackinac, and the initiation of the present stage of Lake Michigan has been the erosion of the lake bluff and the southward transportation of the products of this erosion, while permanent deposition along shore has taken place at very few points in this vicinity and in but small amounts, as may be seen by the deposits along the present beach and on the north sides of the piers and breakwaters projecting into the lake.

Stream and marsh deposits.—The work of the streams began upon the land as soon as it was free from glacier ice and the attendant ponded waters, yet comparatively little has been accomplished thus far, and a large part of what has been done consists of erosion. There are few streams, and many undrained or poorly drained tracts in which the growth of vegetation has resulted in the accumulation of more or less muck and peat, with local intermixture of the shells of fresh-water animals.

Below the mouth of Underwood Creek the bottom of Menominee Valley contains more or less alluvial sand and gravel. East of the National Soldiers' Home this material becomes finer and is spread out in an alluvial plain about one-half mile in width. Toward the east this deposit grades into a marsh, where the course of the stream has been artificially determined by dredging and filling.

Test borings made along the lower course of Milwaukee River and on Clinton street and Kinnickinnick River encountered thick marsh deposits. Borings at either end of West Water Street Bridge, near the point of confluence of Menominee and Milwaukee rivers, penetrated a deposit of marsh clay, below more or less sand, to depths of about 49 and 53 feet below the level of Lake Michigan. Borings made to depths of 7 to 20 feet below the lake level along either side of Milwaukee River about 1½ miles north of this confluence penetrated marsh clay with shells. At either end of the Kinnickinnick Avenue Bridge over Kinnickinnick River borings showed that the marsh clay extends to depths of about 26 to 40 feet below the lake. Borings at the intersections of Florida and Clinton streets and Clinton street and National avenue also showed marsh clay extending to depths of 23 and 20 feet, respectively, below the lake.

These facts indicate that at some stage subsequent to the deposition of the red clay the lake waters were drawn down to a level about 50 feet below their present position. This lowering of the lake level greatly increased the gradient of the lower parts of Milwaukee, Menominee, and Kinnickinnick rivers and correspondingly increased their eroding power, so that they excavated their lower courses to the depths indicated. At a succeeding high-water stage the lower valleys were again flooded and the outlets were obstructed by sand bars, causing them to become filled with marsh deposits.

Landslide terraces.—At intervals along the lake bluff north of Milwaukee there are certain terrace-like forms which resemble, more or less closely, slight remnants of ancient lake terraces, but which are the results of landslides. The seepage of water through the porous deposits underlying the red clay renders some of the finer clays very soft; the weight of the overlying mass is then very apt to start the whole mass to creeping on the slippery bed. Sometimes a considerable tract slides down on the beach, carrying the overlying soil and vegetation with it. On reaching the beach the more solid clay lodges banked against the lower part of the bluff face, while its upper surface forms a more or less definite shelf or terrace part way up the slope. Such a terrace is usually distinguishable from a wave-cut terrace by the irregularities of its surface. The terrace-like bench at the lower part of the bluff near the south end of Lake Park and some other like features farther north appear to have been formed in this way.

GEOLOGIC HISTORY.

GENERAL RELATIONS.

The geologic history of the region is written in the several rock formations. Where these are deeply buried and accessible only to the drill they furnish but meager suggestions as to the character and disposition of the rocks, so that general inferences as to these must be derived from adjacent areas. From those formations which are exposed at the surface, and whose beds and fossils can therefore be more carefully studied, much can be learned. The Quaternary deposits, being the latest formed, the best preserved, and the best exposed for study, afford a record from which late geologic history can be deduced in more detail.

The hard-rock formations underlying the drift are all marine deposits, whence it appears that during the several periods of their deposition the Milwaukee area was submerged beneath the waters of the sea. There appear to have been several epochs before the final disappearance of the sea, during which the waters withdrew and the region emerged as land, but evidence as to what took place upon these lands is very meager, indeed. In one or two places there is evidence that the land was exposed long enough for its surface to be carved into hills and valleys by the action of atmospheric agencies. In other places the indications of emergence are chiefly the absence from the series of deposits of certain marine formations that are found in other areas.

PALEOZOIC EVENTS.

During Cambrian time a large part of the interior of the North American continent was beneath the sea. Not all of this interior region, however, was submerged during all of Cambrian time. During the early part of the period the area of Wisconsin must have been land, as the earliest of the Paleozoic formations here are those of later Cambrian time. The incursion of the sea in the later part of this period was from the south, and beneath its encroaching waters the land gradually disappeared until a large part if not all of the area of the State was submerged. In the waters of this sea there accumulated a great deposit of sand, showing the ripple marks and cross-bedding characteristic of a shallow-water deposit. At intervals fine silts commingled with the sand, giving beds of shale, which were then buried by the renewal of the accumulation of sand. In a part of the beds calcareous material commingled with the coarser sediments. In some parts of this region the deposition of calcareous beds once or twice so far superseded the laying down of sands and mud that definite layers of limestone were formed, but a renewed influx of material from the land each time buried the limestone under more sand. So far as is known to the writer, however, these beds of limestone have not been encountered in drilling within the Milwaukee quadrangle. The Cambrian deposits underlie the area at depths of about 1000 to 1200 feet.

At length limestone-forming conditions prevailed, due probably in part to deeper waters and an open sea free from shore sediments. As a consequence the Cambrian sands are overlain by the limestone formation of Cambro-Ordovician age which has been known as the Lower Magnesian limestone. Very generally throughout that part of eastern and southern Wisconsin in which this formation outcrops at the surface there is evidence that before the beds overlying this limestone were deposited the sea withdrew from these parts of the State and the newly formed rock beds were exposed to erosion as a land surface. In consequence of this erosion the formation was considerably dissected, so as to form hills and valleys; and it appears that some of the valleys were cut down entirely through the limestone into the sandstone below.

When deposition was again resumed the sands of the St. Peter formation were laid down upon the uneven floor, filling the old valleys and usually, though not always, overtopping the limestone hills.

After the deposition of the St. Peter sands an open sea gave rise to accumulation of the Trenton and Galena limestone. Where exposed in other areas this formation shows very abundant marine fossils. A prolific fauna also existed during the deposition of the fine silts that compose the overlying Cincinnati shale.

No trace is found here of the earlier Silurian formations, the Medina sandstone, whose most western occurrence has been reported from Michigan, and the Clinton iron ore, which occurs farther north in eastern Wisconsin. In this area the Cincinnati shale is immediately overlain by the Racine limestone.

With the opening of the Silurian period the deposition of the silts of the preceding epoch no longer continued, but instead there were clear-water conditions, developing a new and wonderful fauna, composed of many kinds of marine invertebrates. Among these were a great variety of corals, which had a large part in building the reefs that are represented by the mounds of massive limestone occurring in the midst of the stratified beds. The greater part of the formation consists of the regularly stratified limestone described, but the reefs are unique and interesting phenomena. During his work on the earlier geological survey of Wisconsin Professor Chamberlin made a study of these reefs in the Niagara limestone throughout the eastern part of the State, and in Geology of Wisconsin, vol. 2, pages 368 et seq., gave the following summation of his observations:

It appears, then, that in the southern counties there are three well-marked classes of limestone with intermediate gradations, one class consisting of very irregular, often brecciated or conglomeratic dolomite, forming masses that usually appear as mounds or ridges of rock of obscure stratification; a second class formed of pure, soft, granular dolomites, a part of them calcareous sand rock; and a third class consisting of compact, fine-grained, regular, even beds. We have demonstrated that the three forms change into each other when traced horizontally. They were therefore formed simultaneously. The view that best explains these facts is (1) that the mounds and ridges were ancient reefs, and (2) that the granular sand rock was formed from calcareous sands derived by wave action from the reefs, and (3) that the compact strata originated from the deposit of the finer calcareous mud that settled in the deeper and more quiet waters, the whole process being analogous to, if not identical with, the coral formation of the present seas. * * *

These reefs have yielded many specimens of corals, brachiopods, trilobites, etc., but the nearly horizontal strata in the larger quarries already discussed show only cephalopods and trilobites and these not abundant.

From the distribution of the fossil faunas at the various exposures, Professor Chamberlin concluded—

(1) That upon the reefs there swarmed a great variety of life; (2) that upon certain banks or shoal areas there was also great abundance and variety, among which the crinoid family attained unusual prominence; (3) that over areas of submarine sand flats there either was little life present or, from the porous nature of the rock, it has been ill preserved; and (4) that over the deeper areas, that deposited fine calcareous mud, the gigantic cephalopods held sway.

The occurrence of these ancient reefs is one of the most notable features of the Niagara limestone in Wisconsin.

The alternation of coarse-granular, lumpy-textured strata with those of fine, even grain in the quarries of the Wauwatosa Stone Company may indicate changes of conditions of deposition about these neighboring reefs, due to the rising and falling of the sea level. When the water was deep and undisturbed for long periods over this locality only the finer calcareous muds were carried out and here deposited, but when the sea shallowed, possibly to such an extent as to allow the reef to emerge, the fragmental material produced by wave action was washed out and deposited in the coarser beds now exposed in the quarries. Finer calcareous mud filled the interstices between the grains, and the whole solidified into the coarse-granular, lumpy beds. As the water deepened again, less and less of the coarser material reached these beds, and thus there resulted not only the gradation from the coarse back to the fine, but the actual wedging out of the coarser strata.

The higher (Guelph) beds of the Niagara group near Grafton, 15 or 20 miles north of Milwaukee, and the beds referred to the Cayuga group near Waubakee, 10 miles farther north, together with those provisionally referred to the Cayuga group which occur in the Milwaukee district, complete the Silurian system of eastern Wisconsin. Although there are outlying remnants of the Niagara limestone in southern Wisconsin, showing that its original westward extension was much greater than at present, probably all of the southern part of the State having been submerged in the Niagara sea, yet there is nothing to show that the Cayuga sea transgressed farther west than that part of the lake-border belt where the remnants of the Cayuga beds now occur.

Since none of the deposits that characterized early Devonian time in Michigan occur in Wisconsin it is concluded that the sea withdrew, allowing the whole of the State to emerge. At this time, probably, some of the erosion that dissected the Waubakee and earlier formations occurred.

During the Hamilton epoch of middle Devonian time the hydraulic limestone that is now used in the manufacture of cement was deposited. The armor-plated fishes that inhabited this Devonian sea, which encroached upon eastern Wisconsin, were the first known vertebrate animals among the faunas of the area, though they appeared earlier in other regions. The part of the Milwaukee district now covered by these deposits, as nearly as has been determined, is shown in fig. 2. It is not improbable that their original extension was somewhat greater, though it is doubtful whether a very large part of eastern Wisconsin was submerged by the sea at this time.

The withdrawal of the seas from eastern Wisconsin in Devonian time marks the last of the marine invasions of this area of which any record remains. For the later formations one must go still farther away from the pre-Cambrian nucleus, upon whose flanks were laid the stratified rocks of this and neighboring States. In Iowa, Illinois, Indiana, and Michigan are found the deposits which continue the record through the rest of Paleozoic time.

There is no evidence here of upturnings and foldings of the rock formations such as characterized the close of Paleozoic time in the eastern part of the continent. Here the rock beds are remarkably uniform in position over large areas. The only disturbance to which they appear to have been subjected is very slight warping and tilting consequent on gentle elevations and depressions to which the land was subjected. The dips observed are rarely more than 5°, scarcely enough to measure at the outcrops.

LATER PALEOZOIC, MESOZOIC, AND TERTIARY EVENTS.

During the whole of the enormous interval between the withdrawal of the Devonian seas and the deposition of the drift, so far as is known, the Wisconsin land stood above the level of the sea. There may have been times when the sea waters again encroached upon the area of the State, but no positive evidence of such submergence has been found; yet the work of geological agents did not cease. Denudation now had full sway all over the State, as it had previously over all that part which was not submerged. Not only had much of the crystalline rocks been cut away and the material been spread out in great secondary formations, but each of these sedimentary formations as it emerged from the sea was in turn forced to contribute to the making of succeeding beds, so that much of the original thickness and extension of these formations was cut away.

Rock disintegration and erosion continued until the mantle of the drift deposited on the harder rocks protected them from further extensive destruction. The landscape of this area prior to the deposition of the drift was probably much like that of the driftless area of southwestern Wisconsin at the present time—a region deeply dissected by eroded valleys, where but little of the original upland remained.

QUATERNARY EVENTS.

PLEISTOCENE OR GLACIAL HISTORY.

GENERAL RELATIONS.

The phenomena of the drift here, as elsewhere throughout about 4,000,000 square miles of the northern part of the North American continent (fig. 3), are those characterizing a glacial deposit. The study of these phenomena over a wide range of territory presenting greatly varying features shows that the long interval of erosion following the withdrawal of the Devonian seas from the area of Wisconsin was brought to a close by climatic changes resulting in the development of conditions, in some sense arctic, that prevailed over all the northern part of North America and extended southward into the area of the United States to the latitude of southern Illinois and northeastern Kansas. In consequence of these conditions there were developed the vast continental ice sheets which deposited the mantle of drift that overlies the indurated rock formations.

The thickness of glacier ice required for an advance across a given area depends in large measure upon the direction and declivity of the slope of the surface which it must traverse, the irregularity of that surface, and, if the slope of the surface be in a direction opposite to that of the movement of the ice, as in eastern Wisconsin, it also depends very largely upon the height of the slope which must be surmounted.

In considering what the thickness of the glaciers must have been to have traversed southeastern Wisconsin as they did, we find that the ice advanced westward up a gently rising slope a distance of 20 to 30 miles beyond the present limits of Lake Michigan to the crest of the Niagara limestone. The earlier glaciers surmounted this crest and traversed the lower area beyond. The last glacier in places passed the crest and in other places was obstructed in its advance by an opposing glacier before reaching the crest.

At the shore of Lake Michigan the elevation of the rock surface underlying the drift varies from a few feet above the level of the lake to 60 feet or more below that level. From this elevation the rock surface rises to the west with many undulations until, in the vicinity of Waukesha, Pewaukee, and Genesee, in Waukesha County, 18 to 25 miles from the lake, it stands nearly 300 feet above the lake level. Throughout this area the rock is thickly covered with drift. Lake Michigan in this latitude is 60 to 70 miles wide and 380 to 580 feet deep, as shown by the charts of the United States Coast and Geodetic Survey. The thickness of the lacustrine and glacial deposits over the rock bottom of the basin is unknown, but, judging from the thickness of the drift in surrounding areas and from the amount of material that has been eroded along the shores and borne back for redeposition in the lake, the bottom of the rock basin may be assumed to lie 100 or 200 feet below the bottom of the lake. Thus in a distance of 50 to 60 miles west of the median line of the lake basin there is a rise in the rock surface of 900 to 1100 feet. To reach the limits of its advance in southeastern Wisconsin the bottom of the ice must thus have moved up a slope which, though gentle, was of this height. Nor was this a uniform, smooth slope; the rock surface, as shown by well borings, is uneven, having been cut into hills and valleys before the deposition of the drift.

If the relative altitudes were about the same as at present the thickness of the ice over Milwaukee County must have been great enough to have permitted the glacier not only to traverse the rock but also to overtop all glacial deposits. The highest elevations attained by such deposits in southeastern Wisconsin are 1200 or more feet above the sea. These summits thus stand 600 to 700 feet higher than the rock surface at Milwaukee and 1000 to 1300 feet higher than the bed of the lake to the east. An accumulation of ice 1000 to 1300 feet thick in the lake basin would have given a surface merely on a level with the highest glacial deposits 25 miles to the west, so that, in order to traverse the area, the ice must have attained a thickness considerably greater than this.

EARLIER STAGES OF GLACIATION AND DEGLACIATION.

Of the several drift sheets deposited by the Pleistocene glaciers, it is not certainly known by direct observation that more than one, a late Wisconsin drift sheet, is represented within the Milwaukee district. The occurrence of an older drift sheet in southwestern Walworth County, in Rock County, and in parts of Dane and Green counties, however, whose topographic features and attendant striæ show the direction of movement to have been southwestward to westward, and a large percentage of whose constituent material was derived from the Niagara limestone in the eastern part of the State, makes it almost certain that at least one of the earlier glaciers traversed eastern Wisconsin, including the Milwaukee district (fig. 4). This glacier probably belonged to either the Iowan or the Illinoian stage. Possibly glaciers of both stages crossed this area. Between the glacial stages there were considerable intervals when under milder climatic conditions the ice melted away, new soils were developed by the weathering of the drift deposits, and vegetation grew and vegetal remains accumulated. In the ponded waters that bordered the glacial margins as they lay along the gentle eastward slope of the lake-border tract during the several stages of advance and retreat of the ice sheets, assorted drift was deposited in stratified beds, some of which are now exposed in the slopes of the Menominee Valley.

WISCONSIN STAGE OF GLACIATION.

The disposition of the terminal moraines of the early Wisconsin drift sheet in southeastern Walworth County, Wis., and in northeastern Illinois indicates that an early Wisconsin glacier also crossed this part of southeastern Wisconsin, but the glacial history of the Milwaukee district before the late Wisconsin invasion of the Lake Michigan Glacier can not be determined with much certainty.

During the late Wisconsin glaciation the main axis of the Lake Michigan Glacier lay along the trough of the lake and extended to northwestern Indiana and northeastern Illinois. The directions and the extent of its lateral deployment into the southeastern counties of Wisconsin are shown in fig. 5. The ice crossing the Milwaukee area joined in the vigorous movement consequent on the extension of the Delavan lobe down a pre-Glacial valley which extends southwestward through southern Waukesha and Walworth counties, so that in this vicinity the striæ trend more nearly southwest than those observed either to the north or to the south.

The following observations of glaciated rock surfaces and striations have been made by the writer in the vicinity of Milwaukee:

1. At the quarry of Manegold Brothers, in Menominee Valley near Wauwatosa, two sets of striæ were observed on the nearly horizontal surface of the rock. One set, the coarser and duller, ranges S. 68° W. to S. 72° W. This set is crossed by a second set of fresher and more sharply cut striæ ranging S. 56° W. to S. 64° W. When the quarry was visited a large surface, beautifully polished and striated, was exposed. On this surface were slight offsets of the strata due to faulting. One of these offsets exposed a face 2 inches high fronting northeastward and extending nearly 15 feet across the stripped area. This offset was rounded and smoothed, the striæ running up over the elevation, but offsets that presented south or southwest faces were rough and unmodified, showing conclusively that the movement was from the northeast to the southwest.

2. At Story Brothers' quarry also there were seen two interesting sets of striæ, a fainter and coarser set ranging S. 64° W. to S. 71° W., crossed by a second sharper and fresher set ranging from S. 44° W. to S. 62° W.

3. The rock mound at Moody's old quarry, in the Menominee Valley at Twenty-sixth street, was also well polished on the top and on the eastern slope, but the lee or west side, so far as could be seen, showed no evidence of glaciation. The striæ varied considerably in orientation, the variation being such as would be expected in striæ passing over and around such an obstruction.

4. At Zautcke's quarry, 1½ miles northwest of North Milwaukee, the rock surface showed striæ ranging in direction from S. 20° W. to S. 48° W. The exposed rock was rounded as the crest of a mound. The north and east slopes and the top were well polished and striated, while the south and west slopes were rougher, showing less evidence of glaciation.

In explanation of the sets of crossing striæ observed at the quarries of Manegold Brothers and Story Brothers the following suggestions may be offered. When the west front of Lake Michigan Glacier first crossed the Milwaukee district, its movement was more nearly westward than the later movement, as is shown by the coarser and fainter set of striæ. In this movement the whole ice front in this region joined. When, however, some of the ice crossed the divide and entered the heads of Troy Valley it flowed down this broad, open trough, since it was much easier to do this than to steadily climb the gently rising rock slope. Thus the ice entering this valley flowed faster and farther than the main sheet, which was still confronted by the rising slope, and currents were diverted to the extension of the Delavan lobe. The effects of this diversion were felt as far back as the vicinity of Milwaukee, so that the flow across this area for the remainder of the advance was diverted toward the southwest, the older set of striæ was more or less obscured, and a fresher and more sharply cut set was engraved across them, having a trend more nearly parallel to the direction of the flow of the axis of the Delavan lobe. This excellent example of the effects of local diversion of the ice flow shows that crossing striæ can not safely be regarded as evidence of distinct advances of an ice sheet.

During this advance the great bulk of the drift composing the ground moraine was deposited. This comprises not only the drift of the limited areas indicated as ground moraine upon the map but also much of the drift underlying the marshes, as well as much of the drift underlying the terminal-moraine deposits, which were formed during the subsequent process of deglaciation. At the line marking the limit of the advance there were formed the outer terminal moraine which is distributed through Kenosha and Walworth counties and the interlobate moraine which extends northeastward from the northwestern part of Walworth County (fig. 4). Even when the glacier reached this limit, where its rate of waste equaled its rate of advance, so that its frontal margin halted, the onward flow of the body of the ice continued to bear forward its load of débris to build up the massive accumulation being formed as terminal and interlobate moraines. How long this process continued is not known, but the amount of drift deposit indicates that it must have lasted a long time.

At length, however, when the solstice of the long Glacial winter was passed, the rate of waste gained ascendency over the waning vigor of the advance, and the glacial front was forced backward. This withdrawal from the outer terminal moraines was not, however, a precipitate retreat. Again and again the glacial forces rallied, the ice front halted, and new belts of marginal deposits were formed. When the rate of glacial flow increased or the rate of wasting decreased, or when both of these concurred, the retreating front halted or an actual readvance occurred. It does not appear that the ice was stagnant during the whole process of deglaciation of the area. The inner belts of terminal moraine show considerable concentrations of drift, indicating that at least during those intervals when these ridges were being formed the onward-flowing ice of the body of the glacier was bringing forward débris to be deposited at the glacial margin.

In this way the several ridges of the lake-border belt were successively built up and abandoned.

While the ice front stood at the west ridge in Waukesha and Racine counties the glacial waters either flowed directly to Fox River or were ponded over the low areas west of the ridge. When the ice withdrew from the crest of this ridge the waters flowed southward along the glacial margin to enter the lake basin. In the deposition of these drift ridges the southward-flowing waters bordering the ice front must have had a considerable part, especially in the case of the east ridge, stratified deposits of which are exposed in the lake bluff. Floating ice may also have aided in depositing the less stony upper part of the till. Whether the waters overtopped the drift ridges or whether they were confined to the valley nearest the ice can not now be determined. The absence of definite shore lines above the highest beach of Lake Chicago, however, implies either that there was no extended submergence of their area, or that the water level was gradually shifting, or that a considerable amount of floating ice obstructed wave action.

Between the stage of a marginal stream or lagoon and the definitely marked stages of Lake Chicago there was no real break. As the glacial margin contracted the lake expanded, extending itself northward along the west side of the glacier. During this time also the sag that formed the outlet near Chicago was being cut down, so that the lake level was lowered, and with it was lowered the level of the water in the marginal lagoon.

LAKE CHICAGO AND THE DEPOSITION OF THE RED CLAY.

The Glenwood beach and associated deposits.—When the glacial margin had finally withdrawn from the east ridge of the lake-border system the marginal waters lowered to the level at which the first and uppermost of the recognizable beaches of Lake Chicago was formed. The position of this beach, the Glenwood beach, from a point 6 miles south of the Milwaukee district southward through northeastern Illinois and northwestern Indiana is shown in fig. 8. This figure shows also the location of the Chicago Outlet, by which the lake was drained to Illinois and Mississippi rivers. The Glenwood shore line, as well as those of succeeding stages, has been more or less definitely identified by Mr. Frank Leverett on the east side of the lake as far north as Grand River, nearly opposite Milwaukee, at very nearly the same level.

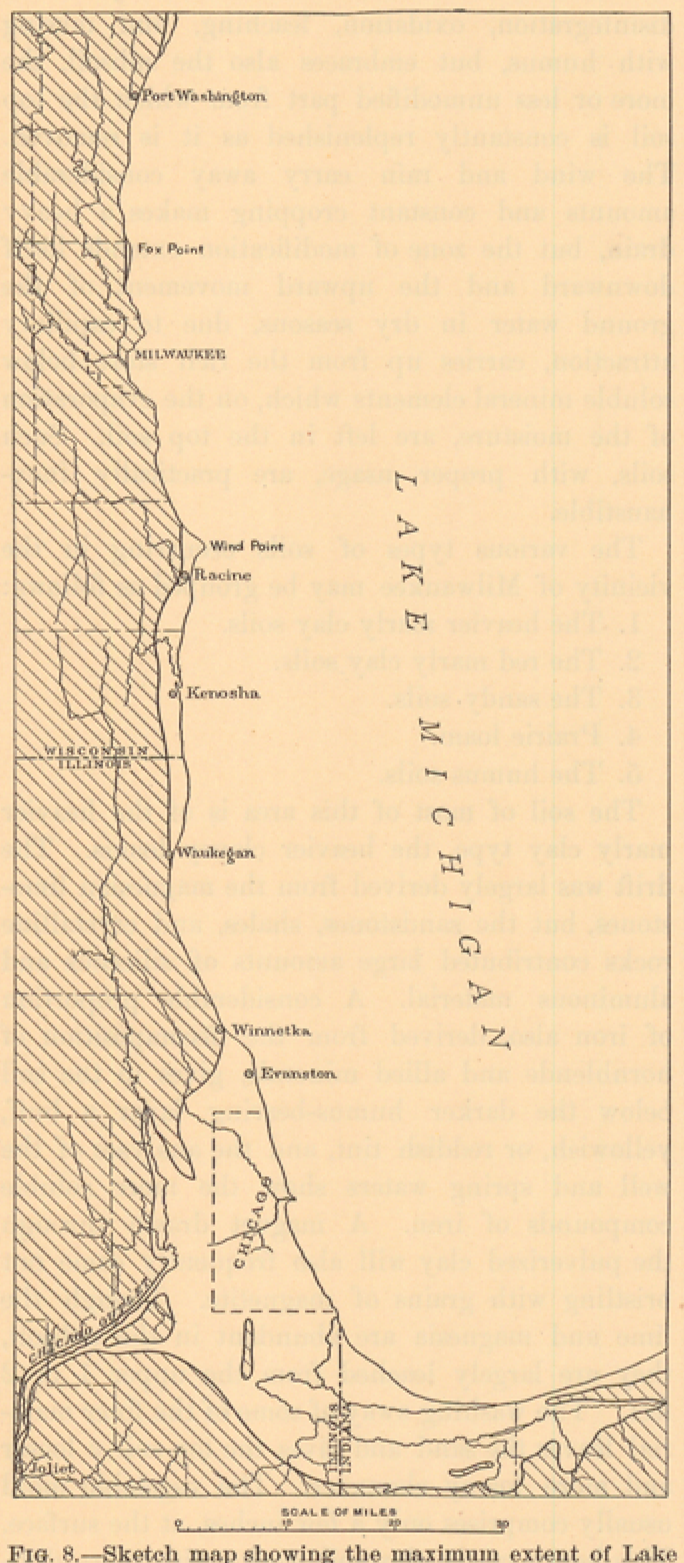


FIG. 8.—Sketch map showing the maximum extent of Lake Chicago, in southeastern Wisconsin, Illinois, and northern Indiana.

Land areas and shore line, where preserved, indicated by shaded area.

At the Glenwood stage, which probably lasted for a considerable time, the waves developed cliffs and terraces where they worked against high ground, and formed beach deposits of sand and gravel where they worked on lower ground. With the coarser material they also formed spits and bars; with the finer they deposited stratified sands and clays. These deposits are well developed in Racine and Kenosha counties, south of the Milwaukee area, but within this district very little of the ancient shore escaped destruction or burial during the succeeding stages of the lake and glacial history.

From the vicinity of Cudahy southward to within $3\frac{1}{2}$ miles of Wind Point, a distance of about 10 miles, the Glenwood shore line lay farther east than the present shore of Lake Michigan and has been entirely destroyed. From the moraine northeast of Cudahy to Kinnickinnick Valley the shore line was probably not far from the position of the small creek, as shown by the stratified deposits bordering the lake in Bayview. From Kinnickinnick River to Menominee Valley artificial grading has so far changed the original surface that there is nothing to indicate the position of the shore.

North of the Menominee Valley, through Milwaukee County and most of Ozaukee County, the Glenwood shore line has nowhere been observed. Farther north slight traces of a beach deposit have been noted by Prof. J. W. Goldthwait at a level corresponding to the Glenwood beach in Racine County. One interpretation of the absence of the Glenwood shore line through so long a distance is that originally it lay farther east than the present lake shore and that it has been cut away by erosion. Another is that it is buried beneath the deposit of red clay, so that its exact position can not now be determined.

It is one view that during the earlier part of the Glenwood stage the glacial front was melted back from the vicinity of Milwaukee, and that in the waters of the lake red clay was being deposited, largely in the form of till, by the melting of the glacier, partly in the form of berg till dropped from ice floating away from the glacial front, and partly as assorted and laminated lacustrine clays more or less interbedded with sands and gravels, a combination of material derived from the landward margin of the lake and that derived from the drift supplied by the glacier. It is further held, under this view, that after these conditions had continued for some time the glacier readvanced as far south as the vicinity of Milwaukee, forcing back the waters of the lake and crowding westward upon the land. Within the Milwaukee district this encroachment of the ice did not extend far beyond the probable position of the Glenwood shore line. It is even possible that in the area west of Whitefish Bay it did not quite reach the shore line, but in the area farther north, in Ozaukee County, the ice must have extended several miles west of any such ancient shore of the lake. This readvancing glacier may have carried up from the bottom of the lake more or less of the reddish deposit now overlying the stratified beds and may have added to it by the continued deposition of red till.

When the ice front was again melted back it was by stages, so that conditions similar to those existing in the lake-border belt previously described prevailed over the area of the red clay, resulting in the formation of a system of parallel ridges marked by gently undulating contours and sparsely sprinkled with bowlders. As the glacial margins continued to contract the lake was extended progressively northward, and at this time may have been formed the slight traces of the Glenwood shore line found north of the Milwaukee area.

Calumet beach.—The beach formed at the next well-defined stage of Lake Chicago has been called Calumet beach, from the relations of Calumet River near Chicago, Ill., to the old shore line. When this beach was formed the water stood at a level 620 to 625 feet above the sea, or 40 to 45 feet higher than Lake Michigan, and discharged through the Chicago Outlet. The Calumet shore line is well developed all about the south end of the lake basin, from Evanston, Ill., where it is cut off by the present lake shore, southwestward to the Chicago Outlet, thence eastward through northwestern Indiana and northward into Michigan. A beach at a corresponding level has been traced by Mr. Leverett with some interruptions northward to Grand Haven, Mich. From Waukegan, Ill., this beach extends northward into Wisconsin, to a point about 7 miles south of the Milwaukee district, where it is cut off by the present shore. From this point northward for a distance of 47 miles no trace of this shore line remains, owing to the encroachment of the lake upon the land during subsequent stages. Within the city of Milwaukee there has been such extensive grading that, as in the case of the Glenwood beach, it is now impossible to trace any old shore line at the level of the Calumet beach.

Low-water stage.—The occurrence of a bed of peat beneath deposits of the Calumet stage at some places in the vicinity of Evanston, Ill., has been regarded as evidence that between the Glenwood and Calumet stages there was a low-water stage during which the waters of the lake were drawn down to a level lower even than that of the present lake, causing an emergence of areas previously submerged and permitting the growth upon them of vegetation and the accumulation of a deposit of peat. This might have resulted if the ice front had retreated so far to the northward as to open a lower outlet. Recently, however, some question has been raised as to whether the peat is really the residuum of vegetation which grew at the place of exposure.

Mr. Leverett has found certain evidence on the Michigan side of the lake which leads him to think a stage of low water may have followed the Calumet stage. (Mon. U. S. Geol. Survey, vol. 38, 1899, pp. 440–443, 446.)

Evidence of a low-water stage is afforded by the examination of the lower courses of Milwaukee, Menominee, and Kinnickinnick rivers at Milwaukee. Attention has elsewhere been called to the fact that borings near the confluence of Milwaukee and Menominee rivers, along the former for a distance of $1\frac{1}{2}$ miles above the confluence, on Clinton street south of the confluence, and near the Kinnickinnick Avenue Bridge show marsh deposits, in some places below more or less sand, extending to depths varying from 20 to 53 feet below the level of Lake Michigan. These facts indicate that at some stage the waters of the lake were drawn down to a level about 50 feet below their present elevation. This lowering of the lake level greatly increased the gradient of the lower parts of these streams, so they excavated their valleys to the depths indicated. Inasmuch as the filling is composed of marsh deposits, sand, and alluvium, and not of red clay, it is inferred that the lowering of the lake level occurred subsequent to the deposition of the red clay. Further than this, however, nothing has been observed indicating the time of its occurrence. It may have preceded or followed either the Calumet or Toleston stage. Certain phenomena observed at Racine suggest, but do not actually prove, that it followed the Calumet stage.

The Toleston and associated beaches.—The cutting down of the southern outlet progressed so far that at length the lake developed a shore line but 20 to 25 feet above the present level of Lake Michigan. This shore line, known as the Toleston shore line, is plainly marked at the south end of the basin leading to the Chicago Outlet. It continues into Indiana, and a beach probably to be correlated with this has been traced, with some interruptions, northward to Grand Haven, Mich. More or less closely associated with this beach in many places are numerous somewhat lower beaches and wave-cut terraces which have not yet been clearly differentiated from the Toleston line. They may represent merely the gradual lowering of the water level due to cutting down of the Chicago Outlet and to adjustments at the northeast which initiated the present stage of Lake Michigan, or they may represent a stage of the lake distinct from that represented by the Toleston beach. Between Waukegan, Ill., and the Wisconsin State line, according to recent studies of Prof. J. W. Goldthwait, the Glenwood and Calumet beaches are well developed, but there is rarely a beach at the level occupied by the main Toleston beach at the south end of the basin—that is, 20 to 25 feet above the present lake level. In place of this there is a well-developed cliff and wave-cut terrace marking a lake level about 15 feet above the present level. For 3 miles north of the State line this cliff and terrace appear to coincide with the higher Toleston shore line. From a point 3 miles south of Kenosha what appears to be the Toleston beach continues northward in a direct line to Kenosha, while a ridge of beach sand and gravel standing 10 to 15 feet above the lake and overlain by dune sand, in places 10 feet thick, diverges slightly to the eastward and is intersected by the present shore 1 mile south of Kenosha Harbor. At this place 1 foot of peat is exposed between the blue till and the overlying beach gravels, suggesting an interval of emergence prior to the development of the beach ridge. Possibly the low-water stage at which the valleys at Milwaukee were cut below the present lake level may be the same as that resulting in emergence and formation of the peat bed underlying the beach gravels south of Kenosha. If this is the case it is probable that the low-water stage occurred after the development of the main Toleston beach and that the lower beach and the terrace at Fox Point represent a later and distinct stage of the lake.

RECENT EVENTS.

With the final opening of the northeast outlet the history of the glacial lake closed and present conditions were inaugurated. From this time the lake is known as Lake Michigan.

Along the west shore of the lake in Illinois and Wisconsin the shore work in recent times has been confined to erosion and transportation, and permanent deposition has taken place in but few places and in small amounts. It is this work of erosion which has cut back the lake shore to its present position, so nearly obliterating all traces of the ancient shore lines in Milwaukee County. The work of cutting back the bluff is going on continually at certain points, as may be seen north of Lake Park, at some points along the Bayview bluff, and south of the mouth of Oak Creek. In some places where the material of the bluff is very easily eroded the rate of cutting has been very rapid.

Since the settlement of the lake-border region this encroachment of the lake upon the land has been a serious menace to property, so that within late years it has been necessary to protect the shore from erosion by building piers and breakwaters at frequent intervals. This artificial interference has greatly reduced the effective work of the waves along the shore. Under the natural conditions the shore drift was considerable. The finer clays were borne backward by the undertow and deposited in the deeper waters off shore. The coarser materials, the gravel, cobblestones, and bowlders, were left along the beach at the foot of the bluff, but the finer sand was transported southward along the shore by the waves and shore currents under the influence of the northeast winds. A large part ultimately reached the head of the lake, where it made new land or was blown up into great sand dunes. Now, however, much of this southward-moving drift lodges on the north sides of the piers projecting into the lake. Several acres of such accumulated sand have been made into a small park at the pumping station for the sewer flushing tunnel.

This southward drift of sand along the shore builds bars across the mouths of streams flowing into the lake, deflecting the waters of the streams southward along the shore behind the bars. This is well illustrated by the conditions on Milwaukee River prior to 1843, when work was begun on the present harbor inlet. (See fig. 9, on next page.)

The present location of the shore line through Milwaukee County was determined by many factors, some of which it may be interesting to note. The position of the shore at the opening of the Glenwood stage was determined by the relation between the water level and the topography left by the glacier. Where much sand and loose soft clay occurred in the bluff, as in the shores of Whitefish Bay and Milwaukee Bay, erosion by the waves was easy and the bluff receded rapidly. Where dense, solid till occurred the erosion was much slower and a salient resulted. Where the rock outcropped at the water's edge, as at Wind Point, north of Racine, the recession of the shore line practically ceased and a prominent point resulted. Near Milwaukee the relation between the topography and the constitution of the bluff section appears to be such that what seem to have been initial sinuosities of the shore line have been perpetuated rather than obliterated. It is also noticeable that the changes in material from the top to the bottom of the bluff have had an influence on the rate of erosion during the successive stages of the lake, so that where active erosion was going on at one stage in the softer beds 20, 40, or 60 feet above the lake, little or no erosion of the more resistant beds lower in the bluff took place at a later stage. This is illustrated by the continuance of the Fox Point terrace.

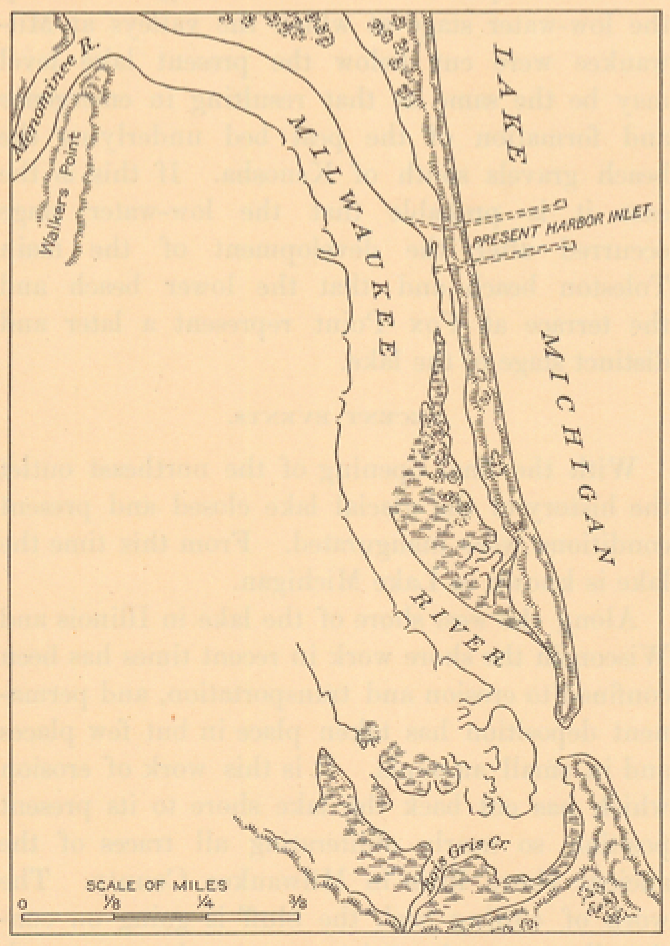


FIG. 9.—Map of the lower course of Milwaukee River in 1836.

Showing the bar behind which the river was deflected southward and the location of the present harbor inlet which is cut through this bar.

From map accompanying the report of the U. S. Army Engineers, Senate Doc. No. 316 [175], Twenty-fifth Cong., 2d sess., 1837-38, p. 1.

Over the area in discussion the work of stream erosion has been comparatively small since the retreat of the glacier. There are very few brooks and many marshy areas, some of which have been artificially drained. Owing to the trend of the topography but little drainage goes directly to the lake, and the recession of the bluff has been so rapid that it is cut by few ravines. The most notable stream work is the excavation of the lower part of Menominee Valley, which was accomplished at the low-water stage of the lake. Doubtless the large amount of sand, gravel, and loose clay in the drift along the line of this valley had much to do with the amount of erosion accomplished.

The course of Milwaukee River through Milwaukee and Ozaukee counties was probably established by drainage along the front of the glacier while the red clay was being deposited. The ponding of the waters behind the ridge of drift at Berthelet caused the formation of the broad, sandy flat which borders the river north of that place. When the stream cut through the drift barrier a new flood plain was developed about 15 feet below the broad flat. The moderate slopes of the valley between the dam and the junction with the Menominee are due very largely to artificial grading. It is said that when the region was first settled steep slopes bordered the marsh through which the stream flowed in this part of its course. With the growth of Milwaukee the slopes were cut down and the marsh was filled.

ECONOMIC GEOLOGY.

MINERAL RESOURCES.

Building stone.—The building-stone industry of Wauwatosa has been fully discussed in a bulletin by Mr. Ernest R. Buckley (Bull. Wis. Geol. and Nat. Hist. Survey No. 4, 1898, pp. 298–309), from which a large part of the following data is taken.

The general character of the stone at the Wauwatosa quarries has already been discussed under the heading "Descriptive geology." The first quarry was that of Story Brothers, opened about the year 1855. The limestone can be quarried in large blocks and is uniform in color and free from all impurities. That taken from some layers dresses beautifully, although not so easily as an open, porous stone. The finished stone has a good appearance and is satisfactory for the finest constructional work.

Microscopic examination shows that the limestone is finely crystalline and very compact and that it is composed for the most part of irregular interlocking crystals of calcite and dolomite. An occasional grain of quartz was the only other constituent observed. The stone is free from all microscopically determinable constituents that might be injurious.

Physical tests of samples from Story Brothers' quarry to determine the strength and durability of the Wauwatosa stone gave the following results:

Physical characters of Wauwatosa stone.

Average specific gravity		2.823
Average porosity	per cent	6.40
Ratio of absorption	do.	2.41
Average crushing strength of 2-inch cubes, per square inch, on bed	pounds	18,397
Average crushing strength of 2-inch cubes, per square inch, on edge	pounds	18,575

This low crushing strength is not due to any inherent weakness of the stone, but to the fact that the samples were hammer dressed. Other samples, which were sawed, gave a crushing strength of over 25,000 pounds per square inch. The modulus of rupture was determined to be 2,129.5 pounds per square inch. When subjected to alternate freezing and thawing samples of the Wauwatosa stone showed no loss in weight. Samples that were gradually heated in a muffle furnace began to calcine at a temperature of about 1200° F. and were practically destroyed at temperatures above this. Samples treated with carbon dioxide in a moist atmosphere suffered no appreciable loss of weight. The faces of samples treated with sulphurous acid in a moist atmosphere were slightly etched and faintly discolored, but there was no appreciable loss in weight.

These tests afford satisfactory evidence that the stone from this area is suitable for all constructional purposes. It is strong and elastic, gives evidence of durability, takes a pleasing rock-face finish, and can be hammer dressed. Many of the courses work under the hammer with some difficulty, but when the stone is cut it will retain for many years the sharp outlines made by the chisel.

Curbing and macadam.—Curbing and crushed stone for macadam are produced at the Wauwatosa quarries and at a quarry 3 miles northwest of Wauwatosa, and crushed stone is quarried $1\frac{1}{2}$ miles northwest and one-half mile south of North Milwaukee.

Lime and flux.—The Racine limestone, especially in its more porous parts, produces an excellent quality of lime; yet only a small amount is now burned in the Milwaukee area, at a place near Hales Corners. It is also reported that limestone from Wauwatosa and from Greenfield was at one time successfully used as flux in the furnaces at the Bayview Iron Works.

Natural cement.—The deposits of the Milwaukee formation exposed in the bed of Milwaukee River north of the city have been used for making natural cement by the Milwaukee Cement Company

Analyses of Hamilton (Milwaukee formation) cement rock, Milwaukee, Wis.[1]

	Carbonate of lime.	Carbonate of magnesia.	Silica.	Alumina.	Oxide of iron, etc.
No. 1[2]	45.54	32.46	17.56	1.41	3.03
No. 2[2]	48.29	29.19	17.56	1.40	2.24
Layers 2-6[2]	47.55	30.91	13.74	3.95	3.85
Layers 7-11	47.09	24.95	18.77	5.14	4.05
Layers 2-11[2]	45.44	31.27	15.65	4.60	3.04
Washington St. Bridge[3]	45.57	27.67	15.60	.12	.38
Washington St. Bridge[2]	41.34	34.88	16.99	5.00	1.79
Do	40.05	35.82	17.00	5.00	1.80
Average	45.11	30.89	16.61	4.09	3.25

[1] Geology of Wisconsin, vol. 2, p. 396. [2] Analyst, Bode. [3] Analyst, Doremus.

since 1876 with the most satisfactory results. At an exposure on Whitefish Bay a shaft was opened in the bluff several years ago, but not until 1900 was the production of cement begun by the Consolidated Cement Company at that place. The general character of the rock at each of these exposures has already been discussed under the heading "Descriptive geology."

The following analysis of the cement was furnished by the Milwaukee Cement Company:

Analysis of cement made by Milwaukee Cement Company.

Silica	23.16
Alumina	6.33
Iron oxide	1.71
Lime	38.08
Magnesia	18.38
Potash and soda	5.27
Carbonic acid, water, etc	7.07
	100.00

Brick clays.—In the vicinity of Milwaukee there are considerable deposits of clays which are sufficiently free from stony material to be suitable for the manufacture of brick. The stoneless, laminated clays are, however, frequently overlain or underlain by stony clays, sand, and gravel, and pockets of stony material are often found in them, so that care must be used in selecting the clay for brickmaking, and it is necessary to use separators and crushers to remove or comminute the stony material, whose presence injures the quality of the brick. In most of the deposits sufficient sand is either interlaminated with the clays or closely enough associated with them to permit ready mixing in order to give them the desired consistency.

The clays at the different banks are much the same in chemical and mineralogical composition, containing high percentages of calcite and dolomite, moderate percentages of quartz and iron oxide, and low percentages of kaolin. The clay that occurs at or near the surface and that has been subjected to leaching by percolating waters, which have removed the calcite and dolomite, contains a smaller percentage of calcium and magnesium and relatively higher percentages of iron, silica, and alumina than that at lower depths.

The clays are of various colors—light bluish gray or buff, light purplish red, reddish, reddish brown, and chocolate-brown—yet when carefully burned all except the clay from the upper weathered zone produce whitish or cream-colored brick. Where less thoroughly burned the bricks have a pinkish tint, somewhat mottled and streaked. An explanation of this phenomenon was offered by Mr. E. T. Sweet in a paper read before the Wisconsin Academy of Science, Arts, and Letters, in February, 1877. Mr. Sweet suggested that there was possibly a relation between the color of the bricks and the high percentage of calcium and magnesium that is invariably present in the clay that burns to a cream color; that the iron, calcium, and magnesium undoubtedly entered into a combination very similar to certain members of the amphibole group, in which the iron does not appear as coloring matter. Professor Chamberlin suggested that the iron is deprived of its water and fully oxidized at a comparatively moderate temperature, and is then red; but that the union of the lime and magnesia, giving rise to the light color, takes place only at a relatively great heat.

Chemical analyses of Milwaukee brick clays.[1]

[W. S. Ferris, analyst.]

	Burnham Brothers.		Standard Brick Co.
	Howell avenue yard.	West yard.	
H_2O, C	21.37	20.08	19.79
SiO_2	40.17	41.63	43.84
Al_2O_3	9.14	8.51	7.82
Fe_2O_3	3.00	3.40	2.00
CaO	14.49	14.39	15.16
MgO	8.34	8.02	8.03
Na_2O	.34	.54	.62
K_2O	3.06	2.90	2.44
TiO_2	.35	.35	.33
MnO	.09	.23	....
	100.35	100.05	100.03

[1] Buckley, E. R., The clays and clay industries of Wisconsin: Bull. Wisconsin Geol. and Nat. Hist. Survey No. 7, pt. 1, 1901, p. 273.

So far as known no clays occur in this district that are suitable for the manufacture of vitrified or refractory wares.

Six yards in the vicinity of Milwaukee and Wauwatosa, when visited by the writer, were manufacturing soft-mud, stiff-mud, or dry-pressed brick. These yards fully supplied the local demand and have a capacity for much greater production. Several other yards are no longer operated.

Pottery clay.—One pottery in Milwaukee uses buff, bluish, and reddish clays, obtained from various excavations, in the manufacture of flower pots and ornamental work.

Sand and gravel.—Deposits of sand and gravel at many places afford material for building sand and filling and gravel for road material, ballast, and other purposes. Their distribution is indicated in the description of the formations.

Drift copper.—No valuable metallic deposits have been found in this area. The drift contains occasional pieces of metallic copper which have undoubtedly been carried there from the Lake Superior region by the glaciers. The largest piece that has come to the notice of the writer was in the possession of City Engineer Benzenberg. This was found near the corner of Cold Springs and Thirty-fifth streets and weighed $11\frac{3}{4}$ pounds.

SOILS.

The final retreat of the glacier and its attendant waters left on the surface the deposit which has been discussed under the name of drift. This contained a great variety of mineral constituents, derived from a wide range of rock formations, so that it furnishes an inexhaustible supply of the mineral substances needed for plant food. This material, however, was in a crude condition, and not until the sunlight, the rain, and the frost began their work of aeration, disintegration, and chemical reaction was it available for use by plants. Where this process has proceeded farthest in this area the best soil has been produced. The increasing vegetation has in turn added its contribution of organic action and residual humus deposits. The soils are deep, rich, and enduring, and the area is very fruitful in those products to which the climate is adapted.

That which is referred to under the name soil includes not only the soil proper, the upper foot or less of the drift which has been subjected to disintegration, oxidation, leaching, and mixing with humus, but embraces also the subsoil, the more or less unmodified part from which the top soil is constantly replenished as it is removed. The wind and rain carry away considerable amounts and constant cropping makes a heavy drain, but the zone of modification extends itself downward and the upward movement of the ground water in dry seasons, due to capillary attraction, carries up from the rich store below soluble mineral elements which, on the evaporation of the moisture, are left in the top soil. Such soils, with proper usage, are practically inexhaustible.

The various types of soils occurring in the vicinity of Milwaukee may be grouped as follows:

1. The heavier marly clay soils.
2. The red marly clay soils.
3. The sandy soils.
4. Prairie loam.
5. The humus soils.

The soil of most of this area is of the heavier marly clay type, the heavier clayey loams. The drift was largely derived from the magnesian limestones, but the sandstones, shales, and crystalline rocks contributed large amounts of siliceous and aluminous material. A considerable proportion of iron also, derived from the decomposition of hornblende and allied minerals, gives to the soil below the darker humus-bearing layer a buff, yellowish, or reddish tint, and the analyses of the well and spring waters show the more soluble compounds of iron. A magnet drawn through the pulverized clay will also frequently come out bristling with grains of magnetite. Though the lime and magnesia are abundant in the subsoil, they are largely leached from the upper 1 or 2 feet. The washing away of some of the finer material leaves the sand and gives the top soil a looser and more loamy character. The vegetable mold usually comprises only a few inches, at the surface. This heavy marly clay soil works with more difficulty than prairie loam, yet, on the other hand, it works much more readily than the soils of the class next to be described.

The soil of the red-clay area east of Milwaukee River is distinctly different from that of the rest of the area. The clay here is finely comminuted, close, compact, and almost impervious, so that the zone of weathering has extended but a short distance below the surface. The mineralogical constituents are about the same as those of the marly clays just discussed, the difference between the two being largely of a physical nature; the material is finer and the clay is more homogeneous. While the carbonates are pretty thoroughly leached from the upper part, the clay below is almost always highly calcareous. When dug up the clay, instead of pulverizing loosely, falls into little cubical blocks, due to the intimate fissuring of the clay by fine cracks when dry. This soil is duller in color in its upper part and at the immediate surface is of ashen hue. Yet the plow goes usually well below this zone, so that the fields have a decided reddish tinge. The soil is worked with some difficulty and requires thorough and judicious cultivation—the more working the better. The clay is very hard when dry, and if the plow or cultivator is put on when the field is wet, clods are formed which when dry are almost unbreakable. If improperly worked such a soil may be made practically worthless, so far as one season is concerned. The soil is exceedingly strong, durable, and fertile, and cultivation improves rather than exhausts it. The stirring and washing out of the finer materials and the exposure to the air incident to cultivation gives it a lighter and warmer character.

The prairie-loam soils are rich, warm, and easily worked. Of much the same character are the alluvial soils, except that these are apt to be gravelly.

The class of sandy soils is not important since the sandy areas are limited in extent. In all these there is usually sufficient clay mixed with the siliceous sand to form a sandy loam, and a good coat of humus makes them very productive.

There are numerous marsh areas where peat and muck have developed and where both the surface and the subsoil are chiefly of organic origin. These form rich soils for certain types of vegetation if sufficient mineral matter is mixed with the organic product. Some of these areas near the city have been very profitably used in market gardening.

WATER RESOURCES.

Rainfall.—The average precipitation for the thirty years ending in 1900 was 31.59 inches, which equals 272,331.86 barrels per acre. It should be noted, however, that quite as much depends upon the distribution of the precipitation through the year as upon the total amount for the year. The greatest danger to crops lies in a deficiency of rain between June and September, there being many years when the corn and other crops that ripen in the autumn are shortened by drought during this period. During some years heavy rains and low temperature keep the ground cold and wet from April to June; then a reversal of conditions suddenly occurs and the ground becomes baked by the hot, dry atmosphere and blazing sun.

Water power.—The water power of Milwaukee River is utilized at two points in this area, one about 20 feet above the lake, at the Milwaukee dam below the North Avenue Bridge, and one about 100 feet above the lake, at the grist mill 4 miles north of the city.

Water supply of cities and villages.—The city of Milwaukee draws its public water supply from Lake Michigan through a 7½-foot intake tunnel projected 3000 feet through the soft shaly part of the Devonian formations underneath the lake at North Point. This tunnel lies about 130 feet below lake level. At the crib the lake has a depth of 25 feet. From the station at North Point the water is pumped to a large reservoir about 1 mile west of Kilburn Park, which stands about 120 feet above the lake.

The following, from an analysis of the lake water at Milwaukee by Mr. Gustavus Bode (Geology of Wisconsin, vol. 1, p. 308), shows its mineral constituents:

Analysis of the water of Lake Michigan at Milwaukee, Wis.

	Parts per million.
Calcium sulphate	9.00
Calcium bicarbonate	79.00
Magnesium bicarbonate	35.00
Sodium chloride	6.00
Silica	16.00
	145.00

The city of Wauwatosa has a 1357-foot artesian well at the pumping station in the Menominee Valley. This well draws from the Potsdam sandstone and has a full capacity of 337 gallons per minute.

The village of South Milwaukee has a pumping station at the mouth of Oak Creek and draws its public water supply from the lake.

Mineral springs.—In this area there are numerous springs whose waters are suitable for domestic and medicinal use. Some of these may have their sources in the Racine limestone, but most of them derive their waters from the drift. The mineral composition of the drift is so varied that there is abundant opportunity for variation in the mineral constituents of the water.

Spring waters from Eureka Spring and Siloam Spring, both of Milwaukee; from Schweikhardt's Spring, Wauwatosa; and from Hackett's Spring, Hales Corners, have been analyzed by Mr. Gustavus Bode (Geology of Wisconsin, vol. 1, p. 308). These springs were not visited by the writer, so that their exact location can not be given, and it is also possible that they are now known by other names.

Analyses of waters of springs in the Milwaukee district.

[Parts per million.]

	Eureka Spring, Milwaukee.	Siloam Spring, Milwaukee.	Schweikhardt's Spring, Wauwatosa.	Hackett's Spring, Hales Corners.
Sodium chloride	3353.00	16.00	4.00	4.00
Sodium sulphate	266.00	50.00	10.00	19.00
Sodium bicarbonate	130.00	16.00	9.00	8.00
Calcium bicarbonate	409.00	225.00	205.00	151.00
Magnesium bicarbonate	180.00	135.00	154.00	111.00
Iron bicarbonate	....	....	7.00	6.00
Silica	123.00	10.00	35.00	6.00
Alumina	188.00	....	....	2.00
Organic matter	....	....	Trace	....
	4643.00	452.00	424.00	316.00

Elim Spring is 1½ miles west of Brown Deer, on the farm of Mr. Paul Schmidt, the water coming from a gravel bed. The following analysis, made by Mr. Andrew S. Mitchell, August 4, 1896, was furnished by the Elim Spring Water Company:

Analysis of water from Elim Spring, Milwaukee, Wis.

	Parts per million.
Sodium chloride	5.0643
Sodium sulphate	5.3196
Calcium bicarbonate	281.6442
Magnesium bicarbonate	169.1160
Iron bicarbonate	.4679
Alumina	1.1877
Silica	11.7926
Calcium sulphate	16.8192
Total solids	491.4115

The water is reported to be perfectly free from organic pollution and to be desirable for household use. It has been on the market since 1894 or 1895.

The "Soda Lithia" Spring of Mr. J. Koenen, jr., is located on the old Fond du Lac road, about 1½ miles northwest of Fussville. The following analysis made by Prof. W. W. Daniels, of the State University, in 1892 or 1893, shows the character of the water:

Analysis of water from "Soda Lithia" Spring near Fussville, Wis.

	Parts per million.
Sodium chloride	22.8501
Lithium chloride	1.0094
Potassium sulphate	5.6658
Sodium sulphate	11.0626
Sodium bicarbonate	129.2291
Calcium bicarbonate	229.7537
Magnesium bicarbonate	247.8360
Iron bicarbonate	2.4987
Alumina	2.3582
Silica and insoluble residue	13.1911
	665.4547

Other mineral waters from this area on the market are from the Nee-ska-Ra Mineral Spring, Sparkling Spring, and Castalia Spring, all of Wauwatosa, and Silver Sand Spring, of Milwaukee.

Wells in the drift.—The greater number of wells sunk in this area penetrate sand and gravel in the body of the drift. Some of these deposits occur in more or less continuous strata, so as to be reached by adjacent wells; others are probably local accumulations or pockets in the more compact clay. Being loose and open, these deposits become underground reservoirs and many of them furnish excellent water in amounts sufficient for the house and farm. The water usually carries a good deal of lime, often considerable iron, and sometimes sulphur.

Of the wells not reaching rock the greater part are less than 80 feet deep, but some reach a depth of 170 to 180 feet. Many of those that reach rock do not penetrate it, or enter it less than 10 feet. These draw largely from beds at the contact of the drift and the rock, at which horizon gravels often occur. These drift wells have furnished a large part of the water supply since the settlement of the country, but farmers in the southeastern counties of the State are now finding that this source is becoming inadequate.

Shallow wells in the rock.—The Racine limestone supplies a large number of wells in this area with water in abundance and of excellent quality. The wells noted range in depth from 20 to 365 feet and penetrate the rock from 1 to 270 feet. Wells of this class are in general favor in this region for farm use. Although they are usually more expensive than the drift wells, their water is of better quality and their supply is larger and more constant. Wells that have penetrated the Racine limestone rarely go dry. During the last few years many of the drift wells have been deepened so as to draw from the rock. This limestone is generally a good water carrier and can be depended upon to furnish an ample supply at almost any point if penetrated to a moderate depth. So far as known to the writer no surface flows have been obtained from this formation in the Milwaukee area.

Flowing wells in the drift.—A few flowing wells have been obtained in the drift. These are dependent on local conditions. Most of them derive water from a sand or gravel stratum that lies below a retaining roof of compact clay. This stratum must be more or less continuous and must rise from the point of penetration to a height greater than the surface at the curb of the well in order to give hydrostatic pressure sufficient to cause the water to flow at the surface. Adjacent wells penetrating the same water-bearing stratum may affect each other's flow. Thus a well in the SE. ¼ sec. 33, T. 8 N., R. 21 E., flowed at the surface until a well was bored at a point about 80 rods distant, at a somewhat lower level. The second well obtained a flow, but the flow at the first well ceased. Four other wells of this class were noted, one in sec. 6, town of Wauwatosa, one at a place one-fourth mile north of Butler, one at the St. Francis Art Institute, and one on the Green Bay road 1 mile east of North Milwaukee.

Artesian wells in rock.—It is unnecessary to give here an extended discussion of the rock wells of the area. One desiring to make a study of the subject should refer to more extended published works.

The leading conditions upon which artesian flows in this region depend are stated by Professor Chamberlin (Fifth Ann. Rept. U. S. Geol. Survey, 1885, pp. 134–135) as follows:

1. A pervious stratum to permit the entrance and passage of water.
2. A water-tight bed below to prevent the escape of the water downward. (This is not, however, always essential.)
3. An impervious bed above to prevent its escape upward, for the water, being under pressure from the fountain head, would otherwise find relief in that direction.
4. An inclination of these beds so that the edge at which the waters enter will be higher than the surface at the well.
5. A suitable exposure of the edge of the porous stratum so that it may take in a sufficient supply of water.
6. An adequate rainfall to furnish this supply.
7. An absence of any escape for the water at a lower level than the surface at the well.

These conditions are found in the rock formations of eastern Wisconsin. The pervious strata are the St. Peter and Potsdam sandstones. The retaining roof of the St. Peter sandstone is formed by the lower compact strata of the Trenton limestone. From Elm Grove westward the Lower Magnesian limestone is usually present as the retaining roof of the Cambrian sandstone, but east of that point, according to Mr. F. M. Gray and others, the limestone is absent. A stratum of soft reddish shale or marl occurs near this horizon at Miller's brewery and at the E. P. Allis Company's works, but this is not always present.

Mr. Gray states that below the bottom of the Trenton limestone he usually finds nothing but sandstone in the Milwaukee area, so that the Milwaukee, Wauwatosa, and Cudahy wells find but one continuous water-bearing stratum below the Trenton limestone.

The bottom of the Cambrian sandstone has not been reached in this part of the State, though it has been penetrated several hundred feet, but probably here, as elsewhere, the sandstone rests upon the nearly impervious beds of Archean rock.

As noted in the discussion of the Paleozoic formations and as shown in fig. 1, these formations rise to the west and northwest. The areas of outcrop of the Ordovician and Cambrian sandstones which constitute the collecting areas for the waters drawn upon for artesian flows may be seen by reference to a geologic map of Wisconsin. In general that part of these areas lying east of the north-south middle line of the southern half of the State supplies the wells of the eastern part of the State. The collecting areas stand at elevations so high that artesian flows have been obtained at very many points in this part of the State. These formations plunge down beneath the bottom of the lake, so that no natural outlet for the waters is found near this region. The elevations of the junction between the St. Peter sandstone and the Trenton limestone at the outcropping areas, as given by Professor Chamberlin (Geology of Wisconsin, vol. 2, pp. 169–170), may be summarized as follows:

Elevations of the junction of the St. Peter sandstone and the Trenton limestone in the outcropping areas.

Location.	Feet above Lake Michigan.	Feet above sea level.
Rock County	180–433	760–1013
Jefferson County	202–330	782–910
Dodge County	195–368	775–948
Fond du Lac County	297–414	877–994

Where the St. Peter sandstone is separated from the Cambrian sandstone by the Lower Magnesian limestone it is customary to get a higher head from the Cambrian sandstone than from the St. Peter, but where there is no separating stratum there is but one head. There is a popular notion that deepening a well will increase the height at which it will flow. This is not necessarily the case, unless an impervious stratum is passed through and a second porous stratum reached whose collecting area is higher or whose porosity is greater than that of the first. When the water-bearing stratum is once penetrated the head of that stratum will be secured. Deeper boring into the stratum might furnish greater capacity, if a more porous part were reached, but would not necessarily increase the height to which the water would flow. Other things being equal, the greater the distance from the collecting area the lower is the maximum elevation at which flows may be secured. This fact is illustrated by the following list of wells, arranged in order from west to east across Jefferson, Waukesha, and Milwaukee counties:

Elevations of flow from artesian wells in southeastern Wisconsin.

Location.	Approximate elevation above sea.	Approximate head.	Year.	Authority.
	Feet.	Feet.		
Whitewater city well	820	839	1889	T. V. Rogers.
Palmyra "oil" well	828	832	1877	Geol. Wisconsin, vol. 2, p. 161.
Gault farm, near Mukwonago.	820	830	1892	O. Hembrook.
Waukesha city well	810	750	1898	F. M. Gray.
Elm Grove convent	770	790	1898	Do.
Wauwatosa city well	660	687	1898	Do.
Miller Brewing Co	650	710	1898	Do.
E. P. Allis works, Milwaukee.	590	657	1894	Record at office.

Such data as have been obtained concerning the wells in the Milwaukee area are given in the tables on the next page.

By correlating the available data and projecting geologic profiles in different directions, an attempt has been made to determine the elevation of the upper surfaces of the St. Peter and Cambrian sandstone formations throughout the Milwaukee area. The results of this determination for the St. Peter sandstone are shown by contour lines on the areal geology map. These lines, which are drawn at intervals of 100 feet vertically, show the depths below sea level at which the sandstone may be encountered in drilling. Comparison with the elevations of the surface as shown by the topographic contours will indicate the depths below the surface at which the sandstone lies in the various parts of the area.

Owing to the general absence of the Lower Magnesian limestone in this vicinity it has not been found possible, with the data at hand, to determine the position of the upper surface of the Cambrian sandstone very satisfactorily. Where the Lower Magnesian limestone is present, as in the Elm Grove and Waukesha wells, the upper horizon of the lower sandstone lies at variable depths below that of the St. Peter sandstone. In the Elm Grove well the top of the Cambrian sandstone is 270 feet below that of the St. Peter; in the Waukesha well it is 140 feet; at Racine it is 148 feet. At the Miller brewery well the base of the red marl, or shale, which probably belongs to the upper part of the Cambrian formation, lies 190 feet below the top of the St. Peter sandstone, while in the E. P. Allis well it is 320 feet below it. In consequence of this variation, the depth at which the lower sandstone will be reached in drilling can not be predicted with such confidence as that to the upper sandstone formation. As already stated, it is reported that where the Lower Magnesian limestone and the red shale are both absent there is one continuous sandstone formation below the base of the Trenton limestone.

In general, so far as may be judged from the data at hand, the elevations to which the water from the Cambrian sandstone will rise in the Milwaukee area lie between 600 and 700 feet above the sea, or 120 to 200 feet above Lake Michigan. Consequently in those parts of the area where the elevation is not more than 700 feet above the sea, as shown by the topographic map, there appears to be good probability of obtaining flows from this sandstone. Mr. Gray states that the water from the well at the convent in Elm Grove rose to a height of 210 feet above the lake, or approximately 790 feet above the sea. This is the highest head which has been reported to the writer in this area. Mr. Story's well and one of those at the National Soldiers' Home, one-half mile farther south, originally flowed with pressures sufficient to carry the water to elevations of about 738 and 766 feet, respectively, but in both these, as in some others, the head has decreased until the wells no longer flow.

The head of water from the St. Peter sandstone is usually somewhat lower than that from the Cambrian sandstone in this region. The 1700-foot well at the Blatz brewery, with a head of 598 feet, probably draws from the Cambrian, while the 800-foot well, with a head of 557 feet, probably draws from the St. Peter sandstone. Whether or not these formations are separated by limestone or shale at this point the writer is not informed.

A decrease in the head of artesian wells may be due to several causes. It can not be due to failure in the supply in this region. The rainfall and the collecting areas are ample and the porous strata are of the best. The multiplication of wells in a given area may, however, cause an excessive drain upon the supply reaching that area. Mr. F. M. Gray states that the head of a well in this region is usually good if there are no other artesian wells within one-half mile, but that the head has decreased somewhat in localities where many of the wells are permitted to flow all the time. If all the artesian wells in Milwaukee are allowed to flow constantly at their full capacity the drain upon the water-bearing strata is great. The interests of all might be conserved by shutting off the flow except when the water is needed. If there is danger of clogging the pipes, sufficient flow could be allowed to prevent such clogging and not draw heavily upon the supply.

A number of wells that flowed for a time have ceased to flow. Among these are the wells at the Soldiers' Home, at Mr. Story's, and Mr. Ludington's.

The water from the St. Peter sandstone is reported to be uniformly good, while that from the lower sandstone, though generally of good quality, is usually higher in mineral salts. Its mineral content is often large enough to make it unfit for certain uses. The following analyses by Mr. Gustavus Bode (Geology of Wisconsin, vol. 2, pp. 31, 164) show that the water from the St. Peter sandstone contains more mineral salts than that from the Cambrian sandstone:

Analyses of artesian water, Milwaukee, Wis.

[Parts per million.]

	Market square well.	Senator W. H. Jacobs well.
Sodium chloride	432.00	10.9769
Potassium chloride	26.00	4.7044
Sodium sulphate	30.00	151.7947
Calcium sulphate	164.00	249.3322
Calcium bicarbonate	369.00	148.9721
Magnesium bicarbonate	361.00	113.6369
Sodium bicarbonate	44.00	....
Iron bicarbonate	....	2.2999
Alumina	....	3.2408
Silica	41.00	40.7713
	1467.00	725.7292

The Market square well draws its water from the St. Peter sandstone at a depth of 1048 feet, while that of Senator Jacobs draws from the Cambrian at a depth of 1200 feet. Water from one of the wells at the National Soldiers' Home, drawing from the Cambrian sandstone, carried 788.348 parts of mineral salts per million, of which 582.692 parts were calcium sulphate. This water corroded the pipes very badly. Water drawn from the Cambrian sandstone by the well at the E. P. Allis Company's works contained 899.7107 parts of mineral salts per million.

February, 1906.

Data concerning artesian wells of Milwaukee, Wis., and vicinity.

[Elevations in feet above sea level; thicknesses in feet. Most elevations and thicknesses given are approximate.]

Location and owner.	Elevation of curb.	Thickness of drift.	Elevation of top of Wilwaukee formation.	Thickness of Wilwaukee formation.	Elevation of contact of Wilwaukee formation and Waubakee limestone.	Thickness of Waubakee limestone.	Elevation of top of Racine limestone.	Thickness of Racine limestone.	Elevation of contact of Racine limestone and Cincinnati shale.	Thickness of Cincinnati shale.	Elevation of contact of Cincinnati shale and Galena limestone.	Thickness of Galena and Trenton limestone.	Elevation of contact of Trenton limestone and St. Peter sandstone.	Thickness of St. Peter sandstone.	Elevation of contact of St. Peter sandstone and Lower Magnesian limestone.	Thickness of Lower Magnesian limestone.	Elevation of contact of St. Peter sandstone and red shale (Lower Magnesian limestone being absent).	Thickness of red shale.	Elevation of contact of Lower Magnesian limestone or of red shale and Cambrian sandstone.	Thickness of Cambrian, so far as penetrated.	Depth of well.	Aquifer.	Capacity in gallons per minute.	Present head (1898-1899).	Original head.	Original pressure at surface, in pounds per square inch.	Source of information.	Remarks.
Lake Park, Milwaukee	670	160	510	122	388	30	358	320	38	180	—142	330	—472	All sandstone below Trenton, 958 feet							2100	Cambrian	....	....	700	....	F. M. Gray	Flowed in 1898.
Market square, Milwaukee	590	170	....	....	....	....	420	267	153	165	—12	253	—265	193	....	....	....	....	....	....	1048	St. Peter	....	....	690	....	Geol. Wisconsin, vol. 2, p. 164.	Filled 4-inch pipe 60 feet above surface. Exact location not given; probably Market square.
E. P. Allis Co., Clinton and Florida streets, Milwaukee.	590	176	....	....	....	....	414	314	100	170	—70	245	—315	250	....	....	—565	70	—635	272	1497	Cambrian	....	....	657	29	E. P. Allis Co.	Data obtained June 6, 1894. Temperature, 53° F.
Miller Brewing Co., Plank road and Thirty-ninth street, Milwaukee.	650	40	....	....	....	....	610	340	270	160	110	330	—220	130	....	....	—350	60	—410	470	1540	....do	....	....	710	....	F. M. Gray.	
Story Bros., Blue Mound road, near Highbury place, Milwaukee.	680	70	....	....	....	....	610	425	185	175	10	250	—240	All sandstone below Trenton, 630 feet.							1550	....do	....	....	738	25	Mr. Story	Flow ceased and well was deepened to 1850 feet. No flow in 1898. Data approximated from tube of samples.
National Soldiers' Home, Milwaukee	660	96	....	....	....	....	564	....	....	....	....	....	....	....	....	....	....	....	....	....	1507	....do	375	....	766	46	Major Hickman	Flow ceased in 3 years; in 1884 temperature 58° F.
																					1720	....do	104	....	700	18	....do	Flow ceased in 8 years; in 1895 mineral salts 46 grains per gallon.
Mr. Dixon, Beloit road and Fortieth avenue, Milwaukee.	660	100	....	....	....	....	560	350	210	175	35	250	—215	All sandstone below Trenton, with 10- to 40-foot beds of red marly rock, 425 feet.							1300	....do	....	....	660	....	Driller at work with F. M. Gray's machine.	Red marly beds occur at intervals in sandstone. Unfinished when visited in 1899. Just flowed at surface.
Wauwatosa waterworks	660	40	....	....	....	....	620	280	340	140	200	320	—120	All sandstone below Trenton, 577 feet.							1357	....do	337	....	687	....	F. M. Gray.	
Mr. Ludington, SW. ¼ sec. 28, Wauwatosa Township.	710	100	....	....	....	....	....	....	....	....	....	....	....	All sandstone below Trenton							1500	....do	....	703	....	....	Mr. Ludington	Gave good flow to third story for 4 years. 1898 head 7 feet below surface. Much mineral salts.
Elm Grove Convent	770	70	....	....	....	....	700	270	430	170	260	320	—60	160	—220	110	....	....	—330	427	1507	....do	....	790	....	....	F. M. Gray.	

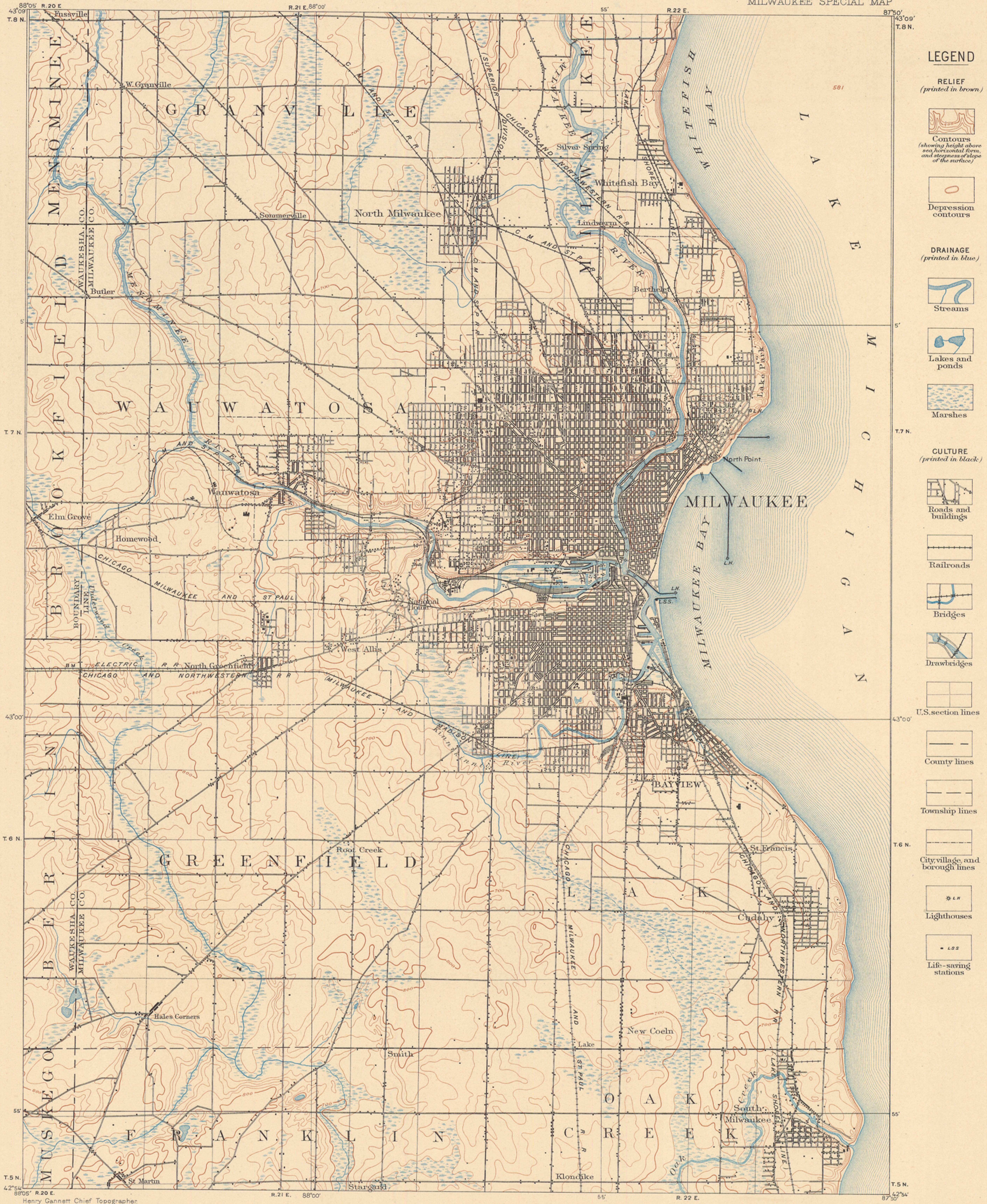
Additional data concerning deep wells in Milwaukee.

Owner.	Location.	Depth.	Depth to rock.	Elevation of curb.	Elevation of water head.	Date.
Blatz Brewing Company	Johnson street	1700	.....	593	598	1900
Do	....do	800	.....	597	557	
E. H. Abbott	Corner Milwaukee and Mason streets	1760	186	.....	.....	1888
Plankington House	Grand avenue, between Second and Water streets	1600	.....	.....	.....	
——Plankington	Loan and Trust Building	1480	.....	.....	.....	1892
George Brunder	Germania Building	1200	.....	.....	.....	1898
Schlitz Brewing Company	Walnut and Third streets	1300	.....	.....	.....	1880
Miller Brewing Company	Plank road and Thirty-eighth street	1604	.....	.....	.....	1903
Forest Home Cemetery	....	1660	165	664	.....	1878-1885
		1621	90	656	656	1886
		1316	100	656	656	1903
Falk Brewing Company	....	1250	.....	.....	.....	
Mrs. Colonel Jacobs	....	1650	.....	.....	.....	
John Johnston	....	1650	.....	.....	.....	
John Mitchell	....	1558	.....	.....	.....	
——McGeogh	....	1200	.....	.....	.....	
Nunnemacher oil distillery	....	940	.....	.....	.....	
Milwaukee insane asylum	....	1700	.....	.....	.....	
Cudahy packing house	....	.....	.....	.....	716	

U.S. GEOLOGICAL SURVEY
CHARLES D. WALCOTT, DIRECTOR

TOPOGRAPHY

WISCONSIN
MILWAUKEE SPECIAL MAP



Henry Gannett Chief Topographer.
Jno. H. Renshawe, Geographer in charge.
Topography by Van H. Manning and Nat. Tyler, Jr.
Shore line by U.S. Lake Survey.
Triangulation by U.S. Coast and Geodetic Survey and U.S. Lake Survey.
Surveyed in 1890 and 1899.

TRUE NORTH
MAGNETIC NORTH
APPROXIMATE MEAN DECLINATION 1906.

Scale $\frac{1}{62500}$

Contour interval 20 feet.
Datum is mean sea level.

DIAGRAM OF TOWNSHIP

Edition of Aug 1906.

U.S. GEOLOGICAL SURVEY
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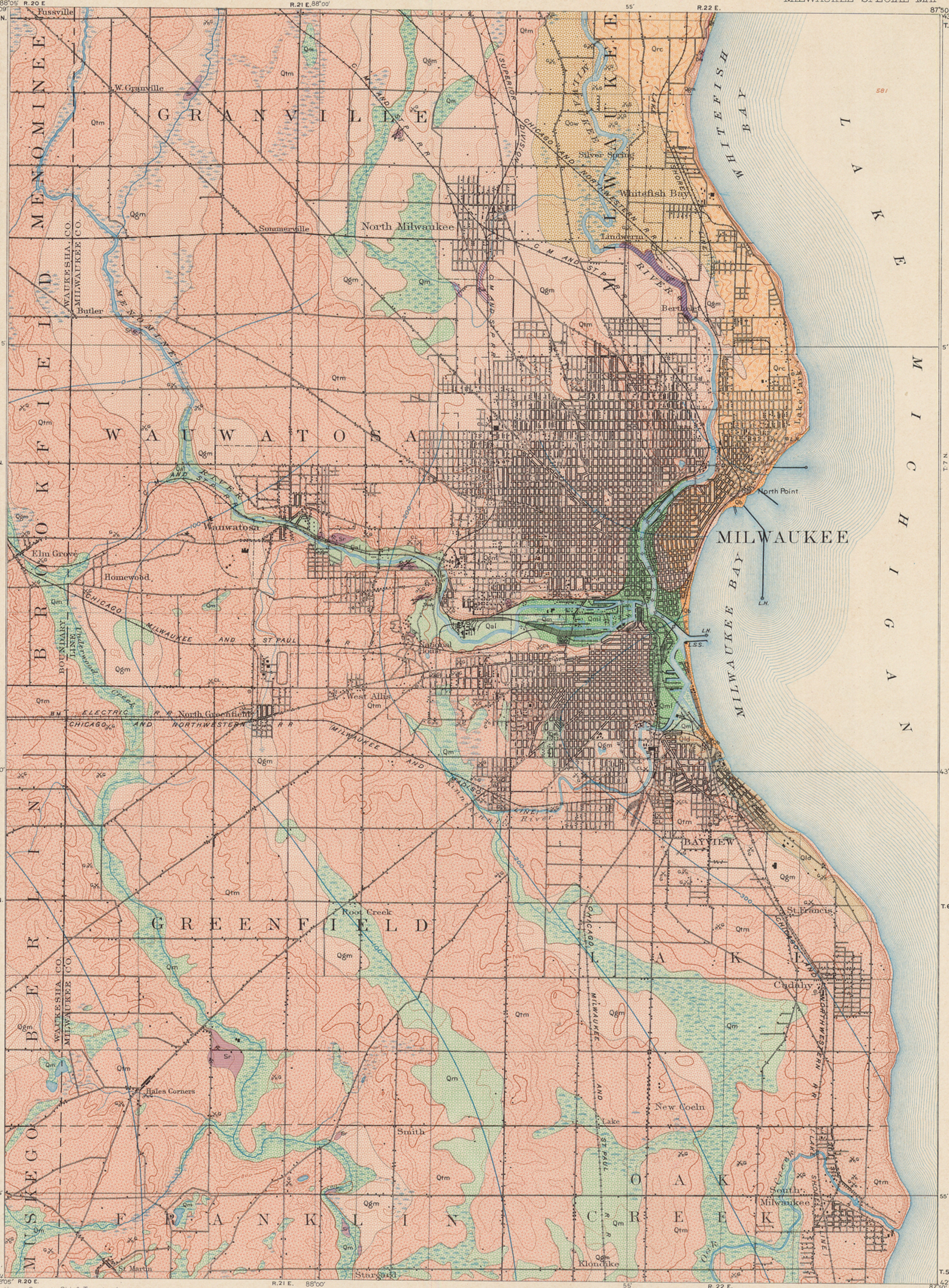
AREAL GEOLOGY

WISCONSIN
MILWAUKEE SPECIAL MAP



LEGEND

SEDIMENTARY ROCKS

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

QUATERNARY

Recent

- Qml — Made land
- Qm — Marsh deposits
- Qal — Alluvium *(flood plain silts, sand, and gravel)*
- Qb — Beach sand

Pleistocene (Wisconsin stage)

- Qld — Deposits of glacial Lake Chicago *(interstratified clay, sand, and gravel, possibly deposited at the Glenwood stage)*
- Qt — Old lake-shore line, wave-cut terrace, and beach sand *(terrace, about 15 feet above present lake level, covered with beach sand)*

Late Wisconsin glaciation

- Qrc — Red pebbly clay *(glacial and lacustrine)*
- Qow — Outwash sand and gravel
- Qtm — Terminal moraines of Lake Michigan glacier
- Qgm — Ground moraine of Lake Michigan glacier

DEVONIAN

Hamilton group

- Dm — Milwaukee formation *(impure magnesian limestone, suitable for manufacture of cement)*

SILURIAN

Cayuga group

- Sw — Waubakee limestone *(thin-bedded magnesian limestone, suitable for road material)*

Niagara group

- Sr — Racine limestone *(massive and heavy-bedded magnesian limestone, used for building stone, road material, and lime)*

Glacial striae
Stone quarries
Clay and gravel pits CL, clay; G, gravel

100 — *Depth of water-bearing strata below sea level* *(approximate depth below sea level of the top of St. Peter sandstone, contour interval 100 feet)*

Wells reaching Cambrian or St. Peter sandstone

Henry Gannett, Chief Topographer.
Jno. H. Renshawe, Geographer in charge.
Topography by Van H. Manning and Nat. Tyler, Jr.
Shore line by U.S. Lake Survey.
Triangulation by U.S. Coast and Geodetic Survey and U.S. Lake Survey.
Surveyed in 1890 and 1899.

TRUE NORTH
MAGNETIC NORTH
APPROXIMATE MEAN DECLINATION 1905.

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 Nov. 1906

DIAGRAM OF TOWNSHIP.

T.C. Chamberlin, Geologist in charge.
Geology by William C. Alden.
Surveyed in 1898 and 1899.

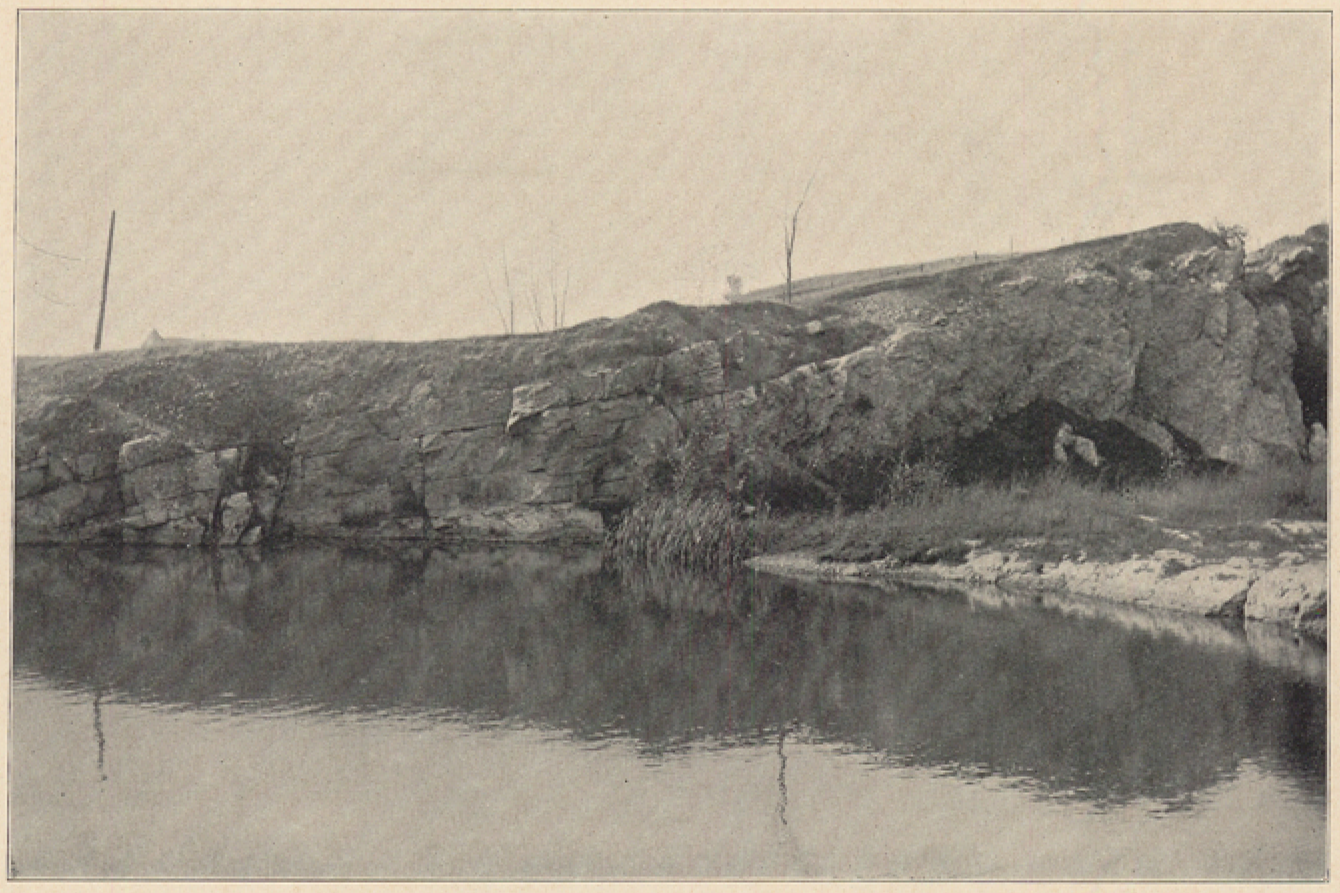


FIG. 10.—RACINE LIMESTONE REEF ROCK IN OLD QUARRY, WAUWATOSA, WIS.

The well-stratified beds at the left merge into the massive irregular-textured limestone that forms the body of the rock mound at the right.

FIG. 11.—OLD WAVE-CUT TERRACE JUST SOUTH OF FOX POINT, WISCONSIN.

Formed at the Toleston stage of Lake Chicago. Ancient lake cliff of till at left. Fox Point in the distance.

FIG. 12.—BUILDING-STONE QUARRY IN RACINE LIMESTONE AT WAUWATOSA, WIS.

FIG. 13.—CEMENT-ROCK QUARRY IN MILWAUKEE FORMATION AT BERTHELET, JUST NORTH OF MILWAUKEE.

FIG. 14.—A TYPICAL SECTION OF GLACIAL DRIFT FROM THE DRIFT AREA OF NORTH AMERICA.

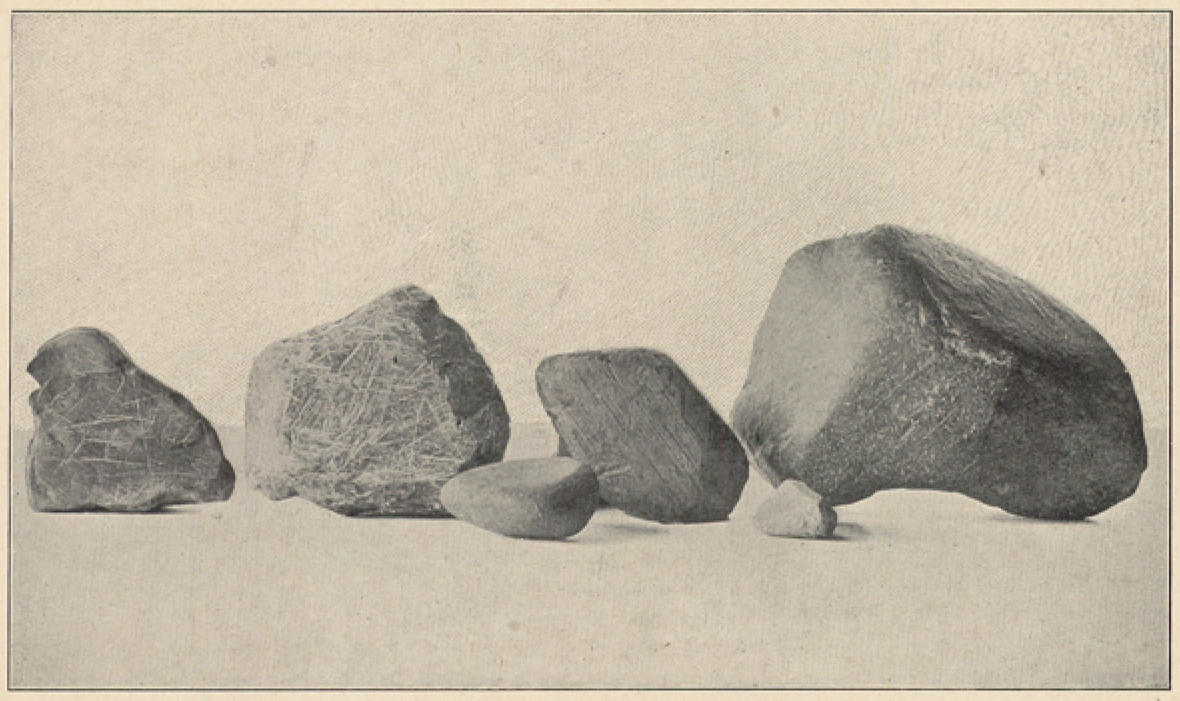


FIG. 15.—GLACIATED PEBBLES FROM THE DRIFT OF NORTH AMERICA.

Characteristic subangular shapes and scratched surfaces.

As sedimentary deposits or strata accumulate the younger rest on those that are older, and the relative ages of the deposits may be determined by observing their positions. This relationship holds except in regions of intense disturbance; in such regions sometimes the beds have been reversed, and it is often difficult to determine their relative ages from their positions; then *fossils*, or the remains and imprints of plants and animals, indicate which of two or more formations is the oldest.

Stratified rocks often contain the remains or imprints of plants and animals which, at the time the strata were deposited, lived in the sea or were washed from the land into lakes or seas, 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. When 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 found 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 often difficult or impossible to determine the age of an igneous formation, but the relative age of such a formation can sometimes 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 is sometimes 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 of their metamorphism.

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.

Symbols and colors assigned to the rock systems.

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

Patterns composed of parallel straight lines are used to represent sedimentary formations deposited in the sea or in lakes. 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 by which formations are labeled 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 recognized series, in proper order (from new to old), with the color and symbol assigned to each system, are given in the preceding table.

SURFACE FORMS.

Hills and 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; sea cliffs are made by the eroding action of waves, and sand spits are built up by waves. Topographic forms thus constitute part of the record of the history of the earth.

Some forms are produced in the making of deposits and are inseparably connected with them. The hooked spit, shown in fig. 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, and these are, in origin, independent of the associated material. 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 afterwards 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. When a large tract is for a long time undisturbed by uplift or subsidence it is degraded nearly to base-level, and the even surface thus produced is called a *peneplain*. If the tract is afterwards uplifted the peneplain at the top is a record of the former relation of the tract to sea level.

THE VARIOUS GEOLOGIC SHEETS.

Areal geology map.—This map shows the areas occupied by the various formations. On the margin is a *legend*, which is the key to the map. To ascertain the meaning of any colored 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 given formation, its name should be sought in the legend and its color and pattern noted, when 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 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.—This map represents the distribution of useful minerals and rocks, showing their relations to the topographic features and to the geologic formations. The formations which appear on the areal geology map are usually shown on this map by fainter color patterns. The areal geology, thus printed, affords a subdued background upon which the areas of productive formations may be emphasized by strong colors. A mine symbol is printed at each mine or quarry, accompanied by the name of the principal mineral mined or stone quarried. For regions where there are important mining industries or where artesian basins exist special maps are prepared, to show these additional economic features.

Structure-section sheet.—This sheet exhibits the relations of the formations beneath the surface. In cliffs, canyons, shafts, and other natural and artificial cuttings, the relations of different beds to one another may be seen. Any cutting which 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 the 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 of the earth to a considerable depth. Such a section exhibits what would be seen in the side of a cutting many miles long and several thousand feet deep. This is illustrated in the following figure:

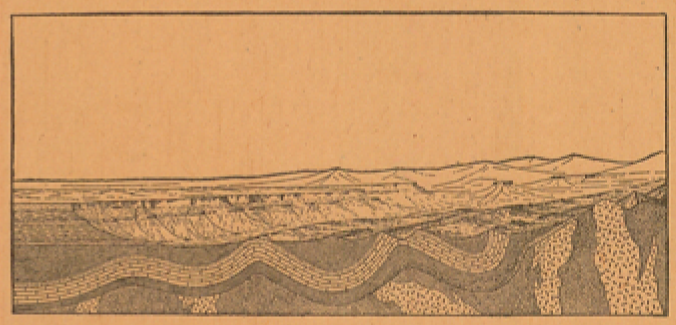


Fig. 2.—Sketch showing a vertical section at the front and a landscape beyond.

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 symbols of lines, dots, and dashes. These symbols admit of much variation, but the following are generally used in sections to represent the commoner kinds of rock:

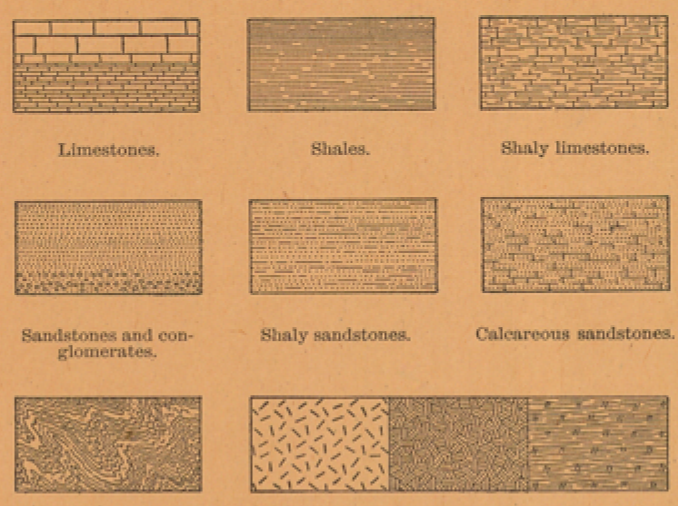


Fig. 3.—Symbols used in sections to represent different kinds of rocks.

The plateau in fig. 2 presents toward the lower land an escarpment, or front, which is made up of sandstones, forming the cliffs, and shales, constituting the slopes, as shown at the extreme left of the section. 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 that the intersection of a bed with a horizontal plane will take is called the *strike*. The inclination of the bed to the horizontal plane, measured at right angles to the strike, is called the *dip*.

Strata are frequently curved in troughs and arches, such as are seen in fig. 2. The arches are called *anticlines* and the troughs *synclines*. But the sandstones, shales, and limestones were deposited beneath the sea in nearly flat sheets; 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 fig. 4.

On the right of the sketch, fig. 2, the section is composed of schists which are traversed by masses of igneous rock. The schists are much contorted and their arrangement underground can not be

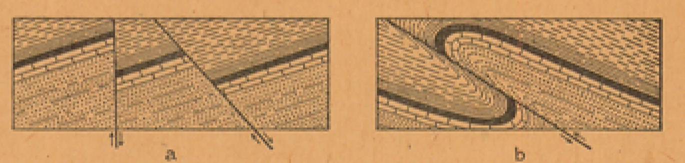


Fig. 4.—Ideal sections of strata, showing (a) *normal* faults and (b) a *thrust* fault.

inferred. Hence that portion of the section delineates what is probably true but is not known by observation or well-founded inference.

The section in fig. 2 shows three sets of formations, distinguished by their underground relations. The uppermost of these, seen at the left of the section, is a set of sandstones and shales, which lie in a horizontal position. These sedimentary strata 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 raised from a lower to a higher level. The strata of this set are parallel, a relation which is called *conformable*.

The second set of formations consists of strata which form arches and troughs. These strata were once continuous, but the crests of the arches have been removed by degradation. 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 at the left of the section. The overlying deposits are, from their positions, evidently younger than the underlying formations, and the bending and degradation of the older strata must have occurred between the deposition of the older beds and the accumulation of the younger. When younger rocks thus rest upon an eroded surface of older rocks the relation between the two is an *unconformable* one, and their 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 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 suffered metamorphism; they were the scene of 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 fig. 2 are ideal, but they illustrate relations which actually occur. 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 which appears in the section may be measured by using the scale of the map.

Columnar section sheet.—This sheet contains a concise description of the sedimentary formations which 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 which state the least and greatest measurements, and the average thickness of each is shown in the column, which is drawn to a scale—usually 1000 feet to 1 inch. The order of accumulation of the sediments is shown in the columnar arrangement—the oldest formation at the bottom, the youngest at the top.

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

CHARLES D. WALCOTT,

Director.

Revised January, 1904.

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115	Kittanning	Pennsylvania	25
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117	Casselton-Fargo	North Dakota-Minnesota	25
118	Greeneville	Tennessee-North Carolina	25
119	Fayetteville	Arkansas-Missouri	25
120	Silverton	Colorado	25
121	Waynesburg	Pennsylvania	25
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