DEPARTMENT OF THE INTERIOR

UNITED STATES GEOLOGICAL SURVEY

GEORGE OTIS SMITH, DIRECTOR

GEOLOGIC ATLAS

OF THE

UNITED STATES

COLUMBUS FOLIO

OHIO

BY

G. D. HUBBARD, C. R. STAUFFER, J. A. BOWNOCKER,
C. S. PROSSER, AND E. R. CUMINGS

SURVEYED IN COOPERATION WITH
THE STATE OF OHIO

WASHINGTON, D. C.
ENGRAVED AND PRINTED BY THE U. S. GEOLOGICAL SURVEY
GEORGE W. STOSE, EDITOR OF GEOLOGIC MAPS   S. J. KUBEL, CHIEF ENGRAVER
1915

GEOLOGIC ATLAS OF THE UNITED STATES.

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

THE TOPOGRAPHIC MAP.

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

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

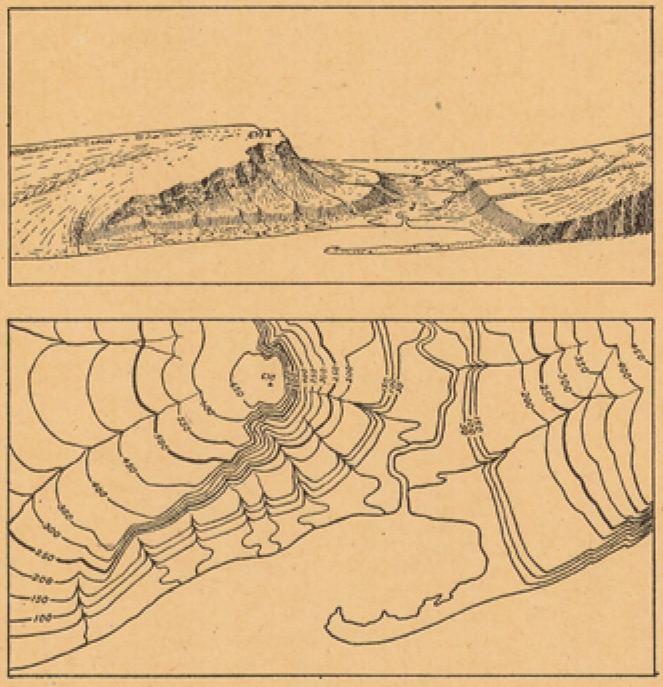

FIGURE 1.—Ideal view and corresponding contour map.

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

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

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

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

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

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

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

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

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

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

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

THE GEOLOGIC MAPS.

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

KINDS OF ROCKS.

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

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

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

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

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

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

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

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

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

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

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

FORMATIONS.

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

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

AGES OF ROCKS.

Geologic time.—The time during which rocks were made is divided into *periods*. Smaller time divisions are called *epochs*,

DESCRIPTION OF THE COLUMBUS QUADRANGLE.

By G. D. Hubbard, C. R. Stauffer, J. A. Bownocker, C. S. Prosser, and E. R. Cumings.[1]

INTRODUCTION.

GENERAL RELATIONS.

The Columbus quadrangle is bounded by parallels 39° 45′ and 40° 15′ and by meridians 82° 45′ and 83° 15′ and comprises the Dublin, Westerville, West Columbus, and East Columbus 15-minute quadrangles, an area of 915.25 square miles. It is in central Ohio (see fig. 1) and includes nearly all of Franklin County and parts of Union, Delaware, Licking, Fairfield, Pickaway, and Madison counties. The city of Columbus is in the center of the quadrangle.

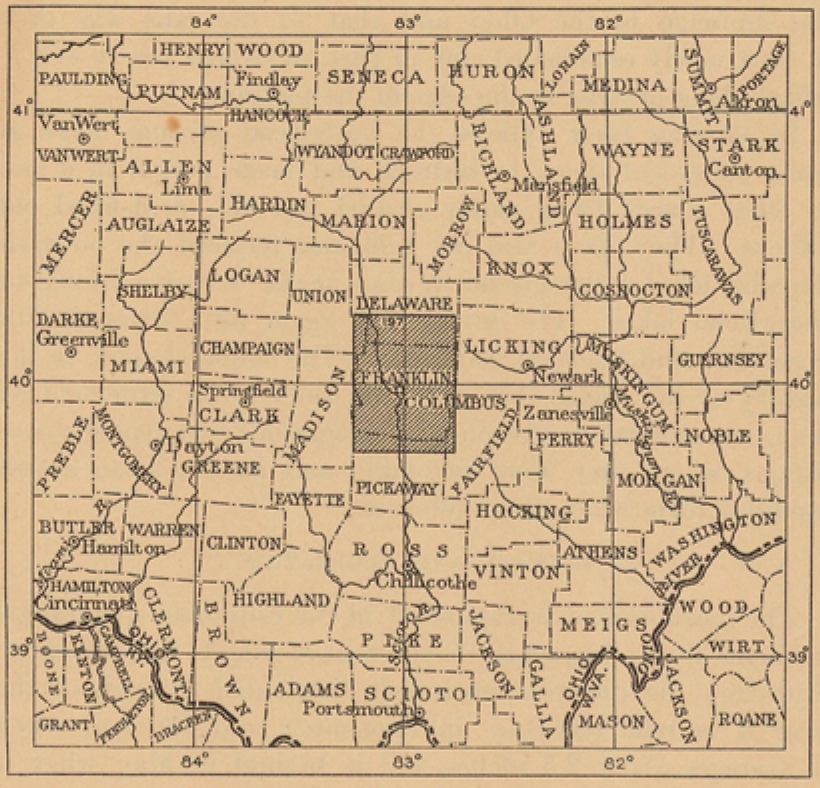

FIGURE 1.—Index map of central Ohio showing location of Columbus quadrangle (ruled area).

In its general geographic and geologic relations the quadrangle forms a part of the rather indefinite border zone in which the Glaciated Plains and the Appalachian province merge. It may equally well be regarded as lying just within the border of the Glaciated Plains or on the northwest flank of the Appalachian province, and it exhibits some of the geologic and topographic features of both.

GENERAL GEOGRAPHY AND GEOLOGY OF THE REGION.

DIVISIONS.

The State of Ohio comprises two major topographic divisions — the Erie Plain in the northwest, occupying about one-fourth of its area, and the Allegheny Plateau in the southeast, occupying nearly all the rest of the State. (See fig. 2.) In the northeastern part of the State these two divisions are separated by a well-defined escarpment, the western continuation of the Portage escarpment of New York, which is apparently traceable southwestward to the Columbus quadrangle, where it is lower and less steep. Thence it extends westward in a very irregular course to the middle of the west side of the State, but west of the eighty-third meridian the plateau and plain are hardly distinguishable as separate features. In Indiana the plain appears to merge westward into the general lowland of the Mississippi basin.

The extreme northwest corner of the State is crossed by the southeastward-facing Marshall escarpment, which separates the Erie Plain from the Thumb upland of Michigan. In the extreme southwest corner of Ohio the Allegheny Plateau merges without a definite escarpment into the Lexington Plain of northern and central Kentucky, although in the east-central part of that State the two divisions are separated by a low escarpment.

The boundary of the area covered by the great ice sheets of the Pleistocene epoch crosses Ohio from the southwest corner to the middle of the east side, about two-thirds of the State, all the northern and western parts, as shown in figure 7 (p. 10), having been glaciated. In Ohio, however, as in Pennsylvania and New York, this line does not coincide with any preglacial physiographic boundary.

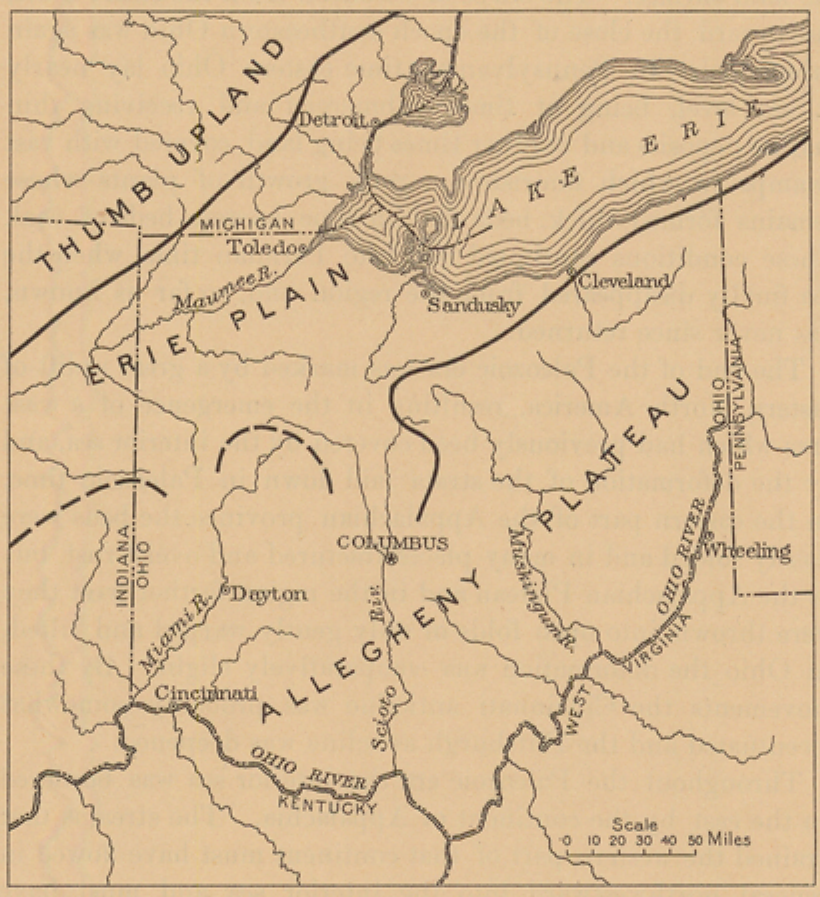

FIGURE 2.—Outline map of Ohio showing physiographic divisions.

RELIEF.

In Ohio the Allegheny Plateau stands between 1,000 and 1,500 feet above sea level, and on the whole slopes westward and southwestward, but it appears to be made up of several minor plateaus that stand at somewhat different altitudes and slope in different directions; hence it is far from regular in altitude or in slope. The highest point, near Bellefontaine, in the west-central part of the State, is 1,550 feet above sea level and one or two other points stand nearly as high.

The plateau is so much dissected by valleys from 200 to 800 feet deep that not much of it remains, and in but few parts of the State is its plateau character evident. In places the floors of the broader and shallower valleys expand into nearly level plains miles in width, broken only by low swells and ridges, chiefly of glacial origin. In other places narrow, steep-sided, more or less V-shaped valleys trench the floors of the broader valleys to a depth of 200 feet or more. The bottoms of these narrower valleys, which lie 500 to 800 feet below the general plateau level and 500 to 700 feet above sea level, are occupied by the present streams.

The escarpment that separates the Allegheny Plateau from the Erie Plain is moderately bold in the northeastern part of the State, where it rises 600 feet or so in 10 or 12 miles from the shore of Lake Erie. It is broken by a few broad valleys that head back in the plateau and is trenched by numerous narrow gorges of streams that flow down the slope to the lake. As far west as Cleveland the base of the escarpment is close to the lake shore, but beyond that place it takes a more southwesterly course and is much less conspicuous. In the western part of the State, where it is low and obscure, it is broken by two broad gaps that extend southward into the valleys of Scioto and Miami rivers.

The part of the Erie Plain within Ohio ranges in altitude above sea level from 575 feet along the shore of Lake Erie to nearly 1,000 feet at some places near the bases of the bounding escarpments. Its relief is slight and it is on the whole a gently rolling plain, interrupted only by low swells and morainic ridges. At its southwest border it merges into the lowland of the Mississippi basin and extends northeastward as a narrow strip along the south shore of Lake Erie into New York. To the north it passes beneath the lake, which is shallow and lies on the plain rather than in it, and reappears to form a great part of the triangular peninsula between Lakes Huron, Erie, and Ontario.

DRAINAGE.

In Ohio the drainage of the Allegheny Plateau, except that of a few small areas along its northwest margin, flows to Ohio River and thence by the Mississippi to the Gulf of Mexico. That of the Erie Plain, on the other hand, flows into Lake Erie and so on to the Gulf of St. Lawrence. The divide between the two drainage basins is rather level and inconspicuous and nearly everywhere lies close to the boundary between the plain and plateau, but several short streams rise on the plateau and flow out through gaps in the escarpment to the plain.

The plateau as a whole is well drained and contains few lakes and swamps except near the divide, where the drainage is not so good and swamps are more abundant. The narrow belt of the Erie Plain in the northeastern part of the State is also well drained, but in the broad, nearly level area in the northwestern part the drainage is somewhat obstructed by glacial deposits and there are several small lakes and many swamps, though swamps are not so numerous as they were before the region was settled and cultivated.

STRATIGRAPHY.

The indurated rocks exposed in Ohio are all of sedimentary origin and of Paleozoic age, ranging from Middle Ordovician to Permian. Their distribution is shown in figure 3. They comprise limestone, dolomite, shale, sandstone, and conglomerate, with beds of rock salt and gypsum in the middle part of the section and beds of coal and fire clay in the upper part, and they have a total thickness of 5,400 to 5,800 feet. They are underlain by strata of Lower Ordovician and Upper Cambrian age, which are not exposed in the State, and the whole series of beds undoubtedly rests on a floor of pre-Cambrian crystalline rocks, such as outcrop beneath the Paleozoic strata in the Lake Superior region, in northern and eastern Ontario, and in the eastern Appalachians.

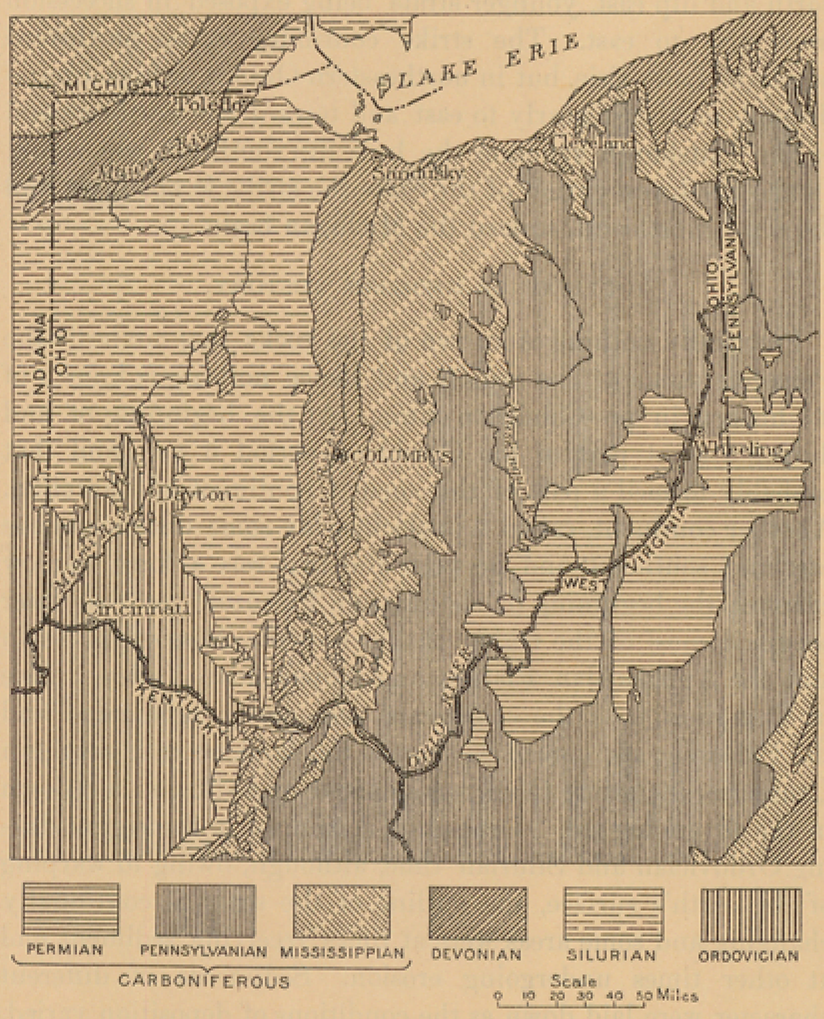

FIGURE 3.—Geologic map of Ohio.
From the geologic map of North America in U. S. Geol. Survey Prof. Paper 71.

Little is known of the character of the Paleozoic rocks beneath the exposed strata, but they probably consist chiefly of limestone and sandstone, as in neighboring regions where they outcrop. The Middle and Upper Ordovician strata exposed in the State are 1,800 feet or more thick and consist in the lower part of sandstone (at the base) overlain by limestone, and in the upper half chiefly of shale. The Silurian strata are 700 to 750 feet thick and consist chiefly of shale in the lower third and limestone and dolomite, with beds of gypsum and rock salt, in the upper two-thirds. The Devonian system includes 200 to 400 feet of Middle and Upper Devonian beds, which rest unconformably on Silurian strata. No strata of Lower Devonian age are known in the State.

All three series of the Carboniferous system are represented in Ohio, although part of the Mississippian is lacking and only the base of the Permian is found. The Mississippian series, about 1,000 feet thick, comprises several formations of shale, sandstone, and fine conglomerate, often collectively spoken of as the Waverly group; and the Maxville limestone, which overlies them unconformably. The Pennsylvanian series comprises 1,200 feet of sandstone and shale, many beds of coal and fire clay, and a few beds of limestone, and is divided into the same four formations—Pottsville, Allegheny, Conemaugh, and

[1] The topography and the Quaternary deposits and the history of the Mesozoic and Cenozoic eras are described by Prof. Hubbard; the Paleozoic rocks and the history of the Paleozoic era by Prof. Stauffer; and the economic geology by Prof. Bownocker. The introduction was prepared largely in the office of the United States Geological Survey. The study of the Paleozoic formations was begun for the United States Geological Survey in 1902 by C. S. Prosser and E. R. Cumings, who mapped those formations in the southern half of the quadrangle. In 1907 the results of their work were transferred by the United States Geological Survey to the Geological Survey of Ohio and the mapping of the quadrangle was completed by C. R. Stauffer. In the preparation of this folio the data obtained by Dr. Prosser and Dr. Cumings, to whom credit should be given on the areal-geology map, have been freely used, but Dr. Stauffer alone is responsible for the part of the text treating of the Paleozoic formations.

Monongahela—as in Pennsylvania. The Permian series is represented by the Dunkard group, of which about 500 feet remains in Ohio. It consists of shale, sandstone, limestone, and a few thin coal beds.

Overlying and in most places concealing the hard rocks in the northern two-thirds of the State is a blanket of unconsolidated glacial drift of Quaternary age, reaching in places a thickness of several hundred feet. South of the drift-mantled area the surface is in places covered by outwash derived from the drift and the larger valleys are bordered by alluvial terraces that contain much material of glacial origin.

STRUCTURE.

The strata must have been deposited in a nearly horizontal position, but they have since been uplifted, tilted in various directions, and warped into low, broad folds. The geologic structure, however, viewed in a large way, is relatively simple. The beds are nowhere closely folded and as a rule the dip is is scarcely perceptible. The main structural features of the region are the Cincinnati anticline and the Pittsburgh syncline. (See fig. 3.)

The Cincinnati anticline is an elongated dome occupying western Ohio, eastern Indiana, and central Kentucky, its principal axis extending from the west end of Lake Erie past Cincinnati to Nashville. The oldest rocks exposed occupy the center of the dome, in northern Kentucky, and successively younger beds outcrop in concentric belts about the central area and dip outward in all directions, but chiefly southeastward, toward the Appalachian basin; westward, toward the Illinois basin; and northward, toward the central Michigan basin. The Pittsburgh syncline is a roughly oval trough occupying southwestern Pennsylvania, southeastern Ohio, and northwestern West Virginia, its axis lying just southeast of Ohio River. The youngest strata occupy the center of the basin and successively older formations outcrop in concentric belts about it and dip inward from all sides beneath the younger beds.

In a wide belt extending northward across the middle of the State and including the Columbus region, which lies midway between the anticline and syncline, the beds strike in general north and dip east, younger strata being exposed in succession from west to east. The strike continues to be northward nearly to Lake Erie, but in northeastern Ohio it swings around through northeast nearly to east and toward the northeast end of the Pittsburgh syncline the beds dip southeast and south. In the northwest corner of the State the strike is northeast and the dip is northwest, toward the Michigan basin.

OUTLINE OF GEOLOGIC HISTORY.

Practically nothing is known of the rocks that underlie the Paleozoic strata of the region and hence nothing is known of its history in pre-Cambrian time. At the beginning of and during a great part of the Cambrian period it was land that probably formed a part of the ancient continent of Laurentia. Another continent, called Appalachia, lay some distance to the east and southeast; and between the two was a long, narrow channel, the beginning of the interior Paleozoic sea that later occupied most of the region that is now the Mississippi basin and the Appalachian Plateau and Appalachian Valley. Late in Cambrian time the continents were partly submerged and the Paleozoic sea spread wide over the land, so that southern Laurentia, including Ohio, was covered by sediment laid down in the advancing sea. Deposition continued in the region during Ordovician and Silurian time, although, owing to warping of the earth's surface, the outline of the sea was continually changing and some areas were at times receiving sediment and at other times undergoing erosion. Sediments of different character were laid down as the conditions of deposition varied, and when the conditions were favorable the sea swarmed with life, abundant remains of which are preserved in some formations. In late Silurian time the sea by relative uplift of the land became shallow, and parts of it became lagoons, from which evaporation was rapid and in which mineral matter was concentrated and deposited as thick beds of gypsum and rock salt.

The close of the Silurian period was marked by an uplift of great extent, by which the sea was much reduced in size or perhaps wholly drained from the Ohio region, and thousands of square miles of recently deposited beds were added to the land area. In western Ohio, eastern Indiana, and central Kentucky the strata were uplifted in a broad, flat arch, the Cincinnati anticline, the formation of which had probably been begun by earlier warpings of the region but culminated at this time. It first rose as an island in the interior sea and later was probably joined to the mainland for a time. As the land emerged the recently deposited sediment was attacked by erosion and part of it was removed, so that when the sea again returned to the region and deposition was resumed the newly deposited strata overlapped the older beds unconformably. This emergence and erosion lasted through early Devonian time.

In Middle Devonian time the sea again spread over the region, the island formed by the Cincinnati anticline was greatly reduced in size though probably never completely submerged, and deposition was resumed. Conditions were not very favorable for the existence of life in the sea, so that organic remains are not abundant in the Upper Devonian rocks. At one time, however, the waters swarmed with great armored fishes, the hard parts of which were entombed in the mud of the sea bottom. From this time until the end of the Paleozoic era the interior sea was never very deep, at least in the Ohio region, and it was on the whole growing smaller and shallower. Owing to the continual slow warping of the earth's surface and the consequent changes in the size, form, and depth of the sea, its margin moved back and forth across eastern Ohio, and erosion nearly everywhere alternated with deposition.

By the beginning of the Mississippian epoch the sea had withdrawn from a part of northern Ohio, but the conditions were such that the streams were depositing alluvial material upon the land surface. The sea soon withdrew from the entire State, but toward the close of the epoch southeastern Ohio was again submerged. In Pennsylvanian time eastern Ohio lay nearly at sea level, being at times submerged and receiving thin marine deposits and at other times being land, covered with vast swamps in which flourished a rank growth of plants whose remains formed thick beds that in time became beds of coal. These conditions continued well into Permian time, when the sea finally disappeared from the region and, so far as known, has never since returned.

The end of the Paleozoic era was marked by a great uplift of eastern North America, resulting in the emergence of a vast area which had previously been covered by the interior sea, and by the deformation of the strata laid down in Paleozoic time. In the eastern part of the Appalachian province the beds were closely folded and in many places fractured and overthrust, but in the Appalachian Plateau and in the region farther west they were thrown into open folds or only gently warped and tilted. In Ohio the deformation was comparatively slight. By these movements the Cincinnati anticline was probably somewhat accentuated and the Pittsburgh syncline was deepened.

Throughout the Paleozoic era the interior sea was bordered on the east by the continent of Appalachia. The streams that drained the western part of that continent must have flowed in general northwestward into the interior sea and must have lengthened their courses in that direction as the land emerged. In the uplift that closed the era the axis of greatest elevation seems to have been well to the east, within the borders of the old continent, and from it the surface must have had a general northwesterly slope, though diversified by local corrugations and by broad swells and basins. In early Mesozoic time, therefore, the master streams that drained the Appalachian Plateau probably flowed northwestward across the region, though their place of discharge into the sea is not known. The surface may have been, and doubtless was, reduced nearly to base level several times and it certainly was so reduced at least once, probably about at the close of the Jurassic period. The peneplain thus formed is called the Cumberland Plain. Apparently it can not be recognized in Ohio. Its formation was terminated by renewed uplift, and by the end of Cretaceous time a large part of the surface was reduced to a new peneplain, represented in Tennessee by the Highland Rim, and in Ohio apparently by the surface of the Allegheny Plateau. The formation of this peneplain was in turn brought to an end by uplift and dissection, but early in the Tertiary period the part of the region now occupied by the Erie Plain was again reduced nearly to base level. In Tertiary time, also, the Allegheny Plateau was dissected and the bedrock surface of the region received nearly its present form. By the unroofing of the Cincinnati anticline in the earlier peneplanations the less resistant older beds had been exposed in the central part of the dome, and in the Tertiary dissection they were reduced more rapidly, thus forming the lower areas of the Lexington Plain.

In the Quaternary period entirely new conditions set in. Great sheets of ice that formed continental glaciers spread outward from centers of accumulation in Labrador and in an area west of Hudson Bay and advanced southward into the United States as far as New Jersey on the Atlantic coast and to the thirty-eighth parallel in southern Illinois. Four, perhaps five, such ice sheets successively invaded the territory west of the Mississippi and at least two of them—the third or Illinoian and the last or Wisconsin—entered Ohio. At the time of its greatest extent the ice covered about two-thirds of the State, in the southwestern corner reaching a little beyond Ohio River. The times of glaciation were separated by interglacial stages during which the climate was warm, perhaps warmer than at present, and the ice sheets melted away entirely from the region and far back into Canada and may, in fact, have wholly disappeared. During the interglacial stages the surface was clothed with vegetation, and huge mammals—some of types now wholly extinct, such as the mammoth and the giant sloth—roamed over the plains.

As the ice advanced it eroded the surface more or less, accentuating the relief in some places and obliterating it in others, and it picked up and carried along a great quantity of stones, clay, and sand. When it melted away, the transported material was in part left where it was deposited by the ice and in part carried away by streams flowing from the ice and deposited as outwash. The mantle of drift left by the ice is in places several hundred feet thick, and in areas of slight relief has formed an entirely new surface, which bears little or no relation to the surface of the underlying bedrock, for it completely filled and obliterated many of the preglacial valleys in that old surface. During each interglacial stage, as well as since the final disappearance of the ice, a new system of drainage was established on the new surface and more or less dissected it. The preglacial drainage of the Allegheny Plateau was northwestward, to the Erie Plain, but as the ice margin retreated across the State from south to north the drainage from the melting ice at first escaped freely to the south, and dissected the surface sufficiently to determine the direction and character of the drainage of the present time. After the ice had left the high ground, however, and its margin was retreating down the northerly slope to and across the Erie Plain, the drainage no longer escaped freely southward but was ponded in a series of small lakes between the ice edge and the plateau. At first these lakes discharged southward through notches in the plateau, but as the ice melted back their levels were lowered and they broadened out and united to form the series of lakes that preceded the present Lake Erie. The divide between the drainage to the Ohio and that to the lake was thus in part newly established and in part uncovered nearly everywhere along or close to the edge of the plateau.

In eroding their valleys the postglacial streams have at some places cut down to bedrock and made gorges in it and at other places have partly cleared out the drift-filled old valleys. They have also cut into and terraced the outwash deposits left by the glacial streams or the deposits formed in the glacial lakes. The surface has again been covered with vegetation and rendered habitable. The latest chapter in the history of the region has been the story of its settlement by man, who has taken advantage of geographic and geologic conditions where they were favorable and has to some extent modified them where they were not.

CLIMATE AND VEGETATION.

The mean annual precipitation in the Columbus quadrangle is about 38 inches, nearly 7 per cent of which falls as snow. Although the precipitation is well distributed throughout the year it is relatively low in September and October, when it averages about 2.5 inches, and is highest in May, when it averages about 4 inches. In some winters from 3 to 6 inches of snow covers the ground for 1 week to 3 weeks. Probably not more than one-third of the precipitation runs off as surface drainage. Much rain falls in prolonged drizzles in the spring, and on the other hand occasional summer droughts last from 2 to 4 weeks. The streams are therefore subject to great fluctuations in flow.

The mean annual temperature is 52° F. and the recorded extremes of temperature are —20° and 104°. The average temperature for January is 29° and for July is 75°. The summer climate is often very trying, as there are occasional periods during which the temperature ranges from 90° to more than 100° and the humidity from 80 to 95 per cent.

The temperature and precipitation make possible the growth of forests, fruit trees, cereals, and vegetables. The region was formerly almost wholly forested but is now nearly deforested, the patches of planted or new wild growth of timber covering not more than 10 per cent of its area.

TOPOGRAPHY.

RELIEF.

General character.—The Columbus quadrangle lies in the Glaciated Plains, its eastern side including the escarpment that forms the western boundary of the Allegheny Plateau in central Ohio. Its surface is level or gently rolling, presenting comparatively slight relief and few prominent topographic features. Its altitude ranges from 670 feet above sea level in the valley of Scioto River, at its south side, to 1,180 feet on one of the group of hills in its southeast corner. The general altitude of the surface is rather lower in the middle of the quadrangle than along the eastern and western sides and decreases gradually from north to south.

Although it forms a part of the Glaciated Plains the quadrangle lacks the variety of glacial features—the rolling surface, with sag and swell, kettle and hummock, lake and swamp—that characterizes much of that province. The surface of the drift mantle is so nearly level and the valleys are so few and young that, aside from one large moraine, most of the area constitutes a remarkably level till plain, broken only by moderate postglacial erosion. The valleys of the main streams that cross the area are, however, topographic features sufficiently conspicuous to warrant somewhat detailed description.

The quadrangle comprises three topographic districts—the highland area along the eastern side, the general upland plain in the northern and western parts, and the lowland plain in the southeastern part. Each district is but a part of a larger similar area, most of which lies outside the quadrangle.

Highland area.—The highland or hilly area owes its altitude and relief to the presence of sandstones and siliceous shales that are more resistant to erosion than the rocks of the rest of the quadrangle. It occupies all the east side of the quadrangle except the broad valley between Pickerington and Canal Winchester, which extends eastward from the lowland plain and separates the highland into two parts. In the southeast corner of the quadrangle an area of about 30 square miles is occupied by a group of hills that collectively form a sort of plateau, whose rather uneven surface ranges generally from 960 to 1,060 feet above sea level, though Chestnut Ridge and a few smaller knobs in the group rise to a height of 1,100 feet or more. The knob on the east margin of the quadrangle, northeast of Greencastle, is the highest point in the quadrangle. Northward and westward from the plateau-like area the surface falls rather abruptly to the lowland plain, into which it merges at altitudes between 860 and 700 feet above sea level, and along this slope it is sharply dissected by many small ravines.

The northeastern part of the quadrangle, a roughly triangular area extending west to Sunbury and south to Pickerington and including about 100 square miles, is also part of the highland. It rises to a height of 1,140 feet above sea level at several points and slopes westward and southwestward to the upland plain, into which it merges at altitudes between 1,000 and 900 feet above sea level. Its surface is broadly rolling, presenting rather gentle slopes, many of which are almost bare rock, as the mantle of soil and drift here is thin. The surface of this part of the quadrangle is not so sharply dissected as that of the southeastern part, and the bounding slope is more gentle and much less uneven in outline. Scattered over it are small, rounded or ovoid hills of drift, or tumuli, ranging in height from 10 to 25 feet.

Upland plain.—The north, northwest, west, and southwest parts of the quadrangle, forming about two-thirds of it, consist of a smooth or gently rolling plain, the general altitude of which ranges from 840 to 960 feet above sea level. This plain is highest in its northwestern part, where its altitude is nearly 1,000 feet, and it slopes slightly southward. The upland surface is not continuous, however, as it is broken by the valleys of the main streams into a number of north-south belts, from 2 to 8 miles wide. The belts of upland that lie east of Scioto River are confined to the northern part of the quadrangle, being terminated on the south by the confluence of the valleys and their broadening to form the lowland plain. A broad belt of upland that lies west of the Scioto extends from north to south entirely across the quadrangle but is somewhat interrupted in the southwest corner by the valley of Darby Creek. The surface on the main divides is almost level, including only a few low swells and shallow depressions. From the divides it slopes gently toward the valleys and is rather closely dissected at their margins. As the valleys converge toward the south the divides also slope gently southward.

A low, irregular ridge, one-half mile to 2 miles wide and in places rising 60 or 70 feet above the general surface, crosses the upland in a sweeping curve past Sunbury, Galena, Africa, Powell, Jerome, and New California. It is the Powell moraine, described under the heading "Stratigraphy." Its top is broad and rolling, is fairly even in altitude, and, unlike that of other moraines in the quadrangle, is broken by no kettle holes. Its southern slope is nearly everywhere much bolder and steeper than its northern slope, and seen from the south it forms a rather conspicuous topographic feature. Other much less conspicuous morainic ridges lie here and there on the upland.

Lowland plain.—The south-central and southeastern parts of the quadrangle, except the highland in the southeast corner, form a lowland plain, which lies between 700 and 800 feet above sea level. This plain is the most nearly level part of the quadrangle, nowhere deeply dissected yet well drained. Some parts of it are almost dead level, and it presents throughout a remarkably even surface, in which a few broad, shallow valleys have been cut. This plain is a part of a broad basin-like valley that enters the quadrangle from the east near Waterloo and leaves it near the middle of the south side.

At a number of places low ridges and hills of glacial origin rise above the lowland surface. Near the east side of the lowland are several low, more or less broken, and as a rule sinuous ridges, which are eskers. They occur near Gahanna, north and also southeast of Brice, and southwest of Canal Winchester. They range in height from 5 to 40 feet, and reach in places a width of 400 feet and a length of 1 mile or more. Other small hills scattered about the lowland, such as Baker Hill, just south of Columbus, which is smoothly rounded and rises 50 feet above the plain, are kames. Spangler Hill, 6 miles south of Columbus (see Pl. I), and a number of neighboring hills form a group of kames, between which lie huge kettles that cover nearly a square mile (see Pl. II). Some of these hills stand 60 to 70 feet above the plain. Another small group of kames and kettles lies about 3 miles north of Canal Winchester.

At several other places there are low drift morainic ridges, with characteristic knob and kettle topography. Such ridges are found east of Columbus, between Reynoldsburg and Brice, northwest and southwest of Groveport, north of Lockbourne, about Waterloo, and southwest of Lithopolis.

Valleys.—The most conspicuous topographic features of the quadrangle are the valleys of the main streams, which cross the upland plain as steep-walled trenches 100 to 160 feet deep and 1 to 2 miles wide at the top. Four such valleys, those of Scioto and Olentangy rivers and Alum and Walnut creeks, enter the quadrangle from the north and extend southward about halfway across it to points where they spread out and merge into the lowland plain. The upland in the southwestern part of the quadrangle is trenched by the valley of Darby Creek, which has an average depth of 80 feet and a width of half a mile to 2 miles. In the lowland the valleys are much less conspicuous, being only 40 to 50 feet deep and having gently sloping sides.

The narrowest and steepest-sided of the main valleys is that of the Scioto north of Marble Cliff. Its width from rim to rim is about a mile where it enters the quadrangle and rather more than 2 miles near Marble Cliff, but it is only a few hundred yards wide at the bottom. At many places it is bordered by nearly vertical bluffs of limestone, 40 to 60 feet high, at others the sides of its valley rise 100 feet in 600 or 700 feet with nearly bare rock surfaces, and many cliffs 10 to 30 feet high are scattered along both sides of the valley. The average steepness of slope is not far from 1 in 40. The valley of the Olentangy has many short, steep slopes and that of Walnut Creek has a few, but both are relatively much broader than that of the Scioto and their slopes are relatively much gentler. The valley of Alum Creek is steep walled in but two places. The average steepness of slope in all three valleys does not exceed 1 in 50 or 60. The valleys of Darby and Little Darby creeks are more trenchlike or boxlike than those of the other large streams, for although the valley walls are generally some distance apart, they are steep and make rather well-defined angular junctions with the till plain above and the flood plain below. Where they cross the lowland plain all the valleys widen greatly, their depth is much diminished, and their side slopes are very gentle except where they have been made steeper by recent cutting. At Columbus the Scioto and Olentangy valleys unite and from that city southward the valley of the Scioto is in places 2 miles or more broad on the bottom.

A fringe of small valleys and ravines dissects the bluff of each of the main valleys. They are abundant along the four main valleys that cross the upland in the northern part of the quadrangle and most abundant along the valleys of Olentangy River and Alum Creek north of the Delaware-Franklin county line. The slope of the ravine walls is rarely gentle, but it differs greatly in different ravines, in different parts of the same ravine, and even in different parts of the same declivity, depending on the material in which the ravine is cut. A good example of variation in grade is seen in the ravine entering the Olentangy Valley from the east, west of Lewis Center. The upper part, which is there cut in shale, is of medium width and has rather gentle side slopes. Farther down, near the forks of the stream, the ravine is cut in softer shale and is correspondingly wider, but from a point a little below the forks to the mouth of the ravine the walls are of limestone and are steep and close together. Many ravines begin in drift with gentle slopes, but their sides get closer together and steeper farther down, where the ravines are cut in rock.

All the main valleys and a few of the minor ones are floored with strips of flood plain, ranging in width from a few hundred feet to nearly 3 miles. The flood plain of the Scioto below its junction with Olentangy River is broad, reaching a width of 2 miles or more in most places, but north of Marble Cliff it is very narrow and at many places is wanting. Olentangy River and Alum, Walnut, and Darby creeks are bordered throughout their courses in the quadrangle by flood plains of irregular width, much broader portions lying here and there, especially at their confluences with other streams.

Out upon the flood plains are built many alluvial fans, which range in width from a few square yards (fans too small to be mapped) to a mile and include compound forms that extend nearly 2 miles along the sides of the main valley. The larger fans are best developed in the valleys of Alum and Walnut creeks; the smaller ones occur by hundreds along the Scioto, Olentangy, Darby, and other valleys. Here and there, as on the east side of Olentangy River a mile or so north of the Delaware-Franklin county line, a large fan of low grade has a smaller, steeper fan built upon it. Some fans have been partly dissected by the streams that built them, and in places material thus removed has been deposited in new secondary fans in front of the older ones.

Terraces are abundant along several of the valleys. Some are formed of superficial deposits, either drift or alluvium; others are cut in rock. Those formed of alluvium are especially well developed in the valley of Darby Creek at Harrisburg, where a group of four terraces having a total height of 28 feet stands out from the west wall of the valley. Similar terraces have been formed in other places, especially in the valleys of the streams that cross the lowland plain. Terraces cut in rock are abundant along Scioto and Olentangy rivers and occur at all altitudes above the streams and at all stratigraphic horizons. The railroad station at Marble Cliff stands on such a terrace, 35 feet above the river. (See Pl. III.) On the east side of the river at Dublin a rock terrace that stands 30 to 40 feet above the stream is 20 to 200 yards wide. The rock terraces have been described in a recent paper[1] from which the summary in the following paragraph is compiled.

All the rock terraces slope downstream and most of them toward the river. Almost every one is nearer the river level at its downstream than at its upstream end; therefore the grade of the stream has lessened since the terraces were cut. Furthermore, the highest terraces have the steepest downstream slopes and the lowest have slopes but little greater than the grade of the stream. Rock terraces are developed only where the rock is limestone, either with or without a thin cover of shale. Shale alone does not appear to be well adapted to their formation. At only a few places are such terraces found on both sides of a valley, and where opposing terraces do occur they stand at very different altitudes.

At a number of places in the quadrangle there are short channels, some reaching a length of 3 miles, which were formerly occupied by streams but are now dry or are traversed only by small streams that did not make them. Most of them lie along the sides of the larger valleys or extend across morainic belts. They were formed late in Pleistocene time, mainly by temporary streams flowing from the melting ice, and are treated further under the heading "Geologic history" (p. 12). The locations of the principal abandoned channels are shown on the surficial-geology map.

DRAINAGE.

General character.—Although the quadrangle is in a glaciated region and is extensively mantled with glacial deposits it is well drained and contains no natural lakes or ponds and no swamps except a few small ones that lie in large undrained kettles. Its western third is underlain by limestone and contains many small streams. Some of these are intermittent because of variations in rainfall and the scarcity of springs; others are apparently discontinuous, their water sinking into coarse alluvium or into underground passages in limestone and leaving their channels dry for short distances. In a belt a mile wide along the west side of the Scioto between Bellepoint and Dublin there are many sink holes that open into enlarged joints and crevices, some of which receive the surface drainage of a considerable area and conduct it to the river though others lead away from it. Other sink holes are found about Marble Cliff and in a belt west of Olentangy River.

The quadrangle is drained to the Ohio almost wholly through Scioto River, but the extreme southeast corner, about Greencastle, is drained to the Ohio through Hocking River. In much of the area the main streams flow from north to south in roughly parallel courses, an arrangement characteristic of this part of central Ohio, but they also converge southward, so that the drainage of about four-fifths of the quadrangle reaches the Scioto within the quadrangle.

Many of the streams, especially those that have flood plains, flow in meandering courses. Along the Scioto below Columbus and along lower Darby Creek there are some abandoned channels and oxbows, but such cut-off meanders are rare. Some smaller streams, which are still flowing in narrow valleys that contain little or no flood plain, have well-developed incised meanders.

Streams.—Scioto River, the master stream, enters the quadrangle from the north at Bellepoint, flows across it in a general southerly course, and leaves it at the middle of the south side. In its course through the upland, as far south as Marble Cliff, the grade of the stream is nearly 5 feet to the mile, but from Columbus southward across the lowland plain, where the stream is broader and shallower, the grade is less than 2 feet to the mile. Owing to this low grade and to the large amount of water contributed by Olentangy River disastrous floods sometimes occur along the lowland portion of the Scioto. About one-fourth of the quadrangle is drained directly to the Scioto by short lateral tributaries, the chief of which is Scioto Big Run, which enters the main stream from the west just south of Columbus. The Scioto is joined on the east by the Olentangy at Columbus and by Walnut Creek near Lockbourne.

Olentangy River, the chief tributary of the Scioto within the area, enters the quadrangle from the north, flows almost directly south, and joins the main stream at Columbus. Its course is entirely within the upland and its drainage basin is confined to a belt only 5 miles wide, hence it has no large tributaries within the quadrangle. Its grade is rather more than 5 feet to the mile.

Walnut Creek, which, with its tributaries, Alum and Blacklick creeks, drains the northeastern and eastern parts of the quadrangle, about two-fifths of the whole, joins the Scioto west of Lockbourne. It enters the quadrangle from the north at Sunbury and flows southward through the upland and out into the lowland plain. In this part of its course it has almost no tributaries from the west, but it receives from the east several

[1] Hubbard, G. D., Ohio Naturalist, vol. 9, p. 397.

moderate-sized streams that drain the eastern slope of the highland area. At a point 2 miles south of Zimmer it is joined by Alum Creek from the north and by Blacklick Creek from the east. Alum Creek, which enters the quadrangle from the north at Cheshire and flows southward past the east side of Columbus, drains a narrow belt of the upland and, like the Olentangy, has no large tributaries within the quadrangle. Blacklick Creek, which rises on the west slope of the highland, northeast of New Albany, and flows south and southwest to the confluence of the three streams, drains about half the east side of the quadrangle. From its confluence with the other two streams Walnut Creek takes a meandering southwesterly course across the lowland to the Scioto.

Little Walnut Creek, which drains all the southeastern part of the quadrangle except a small area about Greencastle in the extreme corner, enters the quadrangle from the east near Jefferson, flows westward to Groveport, and turns southward, leaves the quadrangle and joins the Scioto several miles south of the area. It receives several tributaries, both from the north and from the east.

Darby Creek, which drains the southwestern part of the quadrangle, enters from the west near the middle of the western side. For a few miles it flows alternately within and without the area, then swings southeastward past Georgesville and Harrisburg, leaves the southern side of the quadrangle, and joins the Scioto at Circleville, some distance to the south. At Georgesville it is joined by Little Darby Creek and at Harrisburg by Hellbranch Run. The extreme southwest corner of the quadrangle is drained by Opossum Run, a tributary of Deer Creek, which joins the Scioto much farther south.

Falls and rapids.—The grade of many of the lateral tributaries to the main streams of the upland area is so steep that rapids occur at several places along their courses and small falls at a few places. The falls are generally but not invariably due to a hard layer that lies 25 to 30 feet below the top of the Columbus limestone.

Hayden Falls on Hayden Run, which enters the Scioto from the west 8 miles above Columbus, is the best known. The water leaps over a hard layer of limestone after cascading over several beds of less resistant limestone above. Recently the stream has ceased to run over the falls at times of low water, but sinks into joints, opened by solution, some distance upstream, through which it finds its way to the gorge below the falls.

Slate Run, on the east side of the Scioto a mile south of Hayden Falls, has a small double fall. Just opposite Hayden Run is another small fall. Indian Run, which enters the Scioto from the west at Dublin, has two small branches that unite half a mile above its mouth, on each of which is a small fall some distance above the junction. Just west of the new Casparis quarry, on the west side of the Scioto three-fourths of a mile above Marble Cliff, a small stream enters with a 30-foot fall over the topmost layer of the Columbus limestone, above which for 100 yards or so is a rapids due to thin layers of Delaware limestone. Other small falls occur on branches of the Scioto and a few insignificant ones on branches of the Olentangy.

CULTURE.

Columbus, the capital of the State and an important railroad and manufacturing center, with a population in 1910 of 181,511, is the only city in the quadrangle. A number of small towns and villages, the largest of which is Westerville, are scattered about the area, but the population outside of Columbus is essentially rural and is rather evenly distributed.

The chief occupation of the people is agriculture and the greater part of the area is under cultivation. There is considerable manufacturing in Columbus and some large limestone quarries are operated just outside the city.

Steam railroads radiate in every direction from Columbus and connect that city with all parts of the State. Several interurban electric lines extend in different directions from Columbus, only one of which terminates within the quadrangle. The area is closely covered with a network of highways, some of which are laid out along section and township lines, but most of which are governed more closely by the topography. The National Road crosses the quadrangle from east to west, passing through Columbus, and other important turnpikes radiate in several directions from the city. There are at present no navigable waters in the quadrangle, but canals, now abandoned, formerly extended southward and southeastward from Columbus.

DESCRIPTIVE GEOLOGY.

STRATIGRAPHY.

CHARACTER OF ROCKS.

The exposed rocks of the Columbus quadrangle are wholly sedimentary and range in age from Silurian to Quaternary. They comprise indurated strata—sandstone, shale, and limestone—of Paleozoic age, and unconsolidated surficial deposits—till, glacial outwash, lake beds, and alluvium—of Quaternary age. Beneath the outcropping strata there is, as shown by borings, a considerable thickness of Silurian and Upper and Middle Ordovician rocks, which are presumably underlain in turn here as elsewhere in the Mississippi basin by Lower Ordovician and Upper Cambrian strata, the whole resting on a floor of pre-Cambrian rocks. No deep wells of which good records are preserved have been drilled since 1890, and the generalized description of rocks not exposed is based chiefly on the interpretation of old records, such as those of the statehouse well and the Kilbourne & Jacobs Co. well, an interpretation which differs somewhat from that formerly adopted for the same strata. It must be remembered that the formations disclosed by a deep well section can, as a rule, be distinguished and discriminated only in the most general way.

The general character, thickness, and sequence of the Paleozoic formations are shown diagrammatically in the columnar sections forming figures 4 and 5, which are generalized sections for the whole quadrangle. The several formations will be described in chronologic order, the description beginning with the oldest. Although the Paleozoic rocks outcrop at but few places, in ravines, those formations are regarded as exposed that would lie at the surface if the blanket of surficial materials were removed, and the areal-geology map shows, as nearly as possible, the extent of the bedrock surface occupied by each formation. All the formations exposed at the surface are fossiliferous, and characteristic fossils from each are reproduced on Illustration Sheet II.

ROCKS NOT EXPOSED.

ORDOVICIAN SYSTEM.

The lowest rock penetrated by the deep wells at Columbus is a white calcareous sandstone, the upper part of which in some wells is found to be charged with salt and sulphur water. In areas farther south the sandstone contains beds of greenish shale. The whole is correlated by the author with the St. Peter sandstone of the Mississippi Valley region, but the lower half or more is regarded by Ulrich and Bassler as of the same age as the Beekmantown limestone of New York. The thickness of these deeply buried strata at Columbus is not known, but one well penetrated them to a depth of 316 feet. When this well was drilled these sandy beds were believed to be the Potsdam sandstone, but the recent boring at Waverly, Ohio, which extends downward to the pre-Cambrian crystalline floor, shows that the Potsdam and other Cambrian rocks do not occur in central Ohio. The record of the Waverly well, as published by Bassler, begins with 320 feet of sandy dolomite, referred to the Lower Ordovician, above which is the white saccharoidal St. Peter sandstone. Upper Cambrian beds, however, seem to lie upon the pre-Cambrian floor in northwestern Ohio, where there is 470 feet of quartzose and in part arkosic sandstone, with glauconitic and dolomitic sandstone, referred to the Upper Cambrian by Ulrich in a description of two deep wells near Findlay, the logs of which were published in 1913 by Condit.

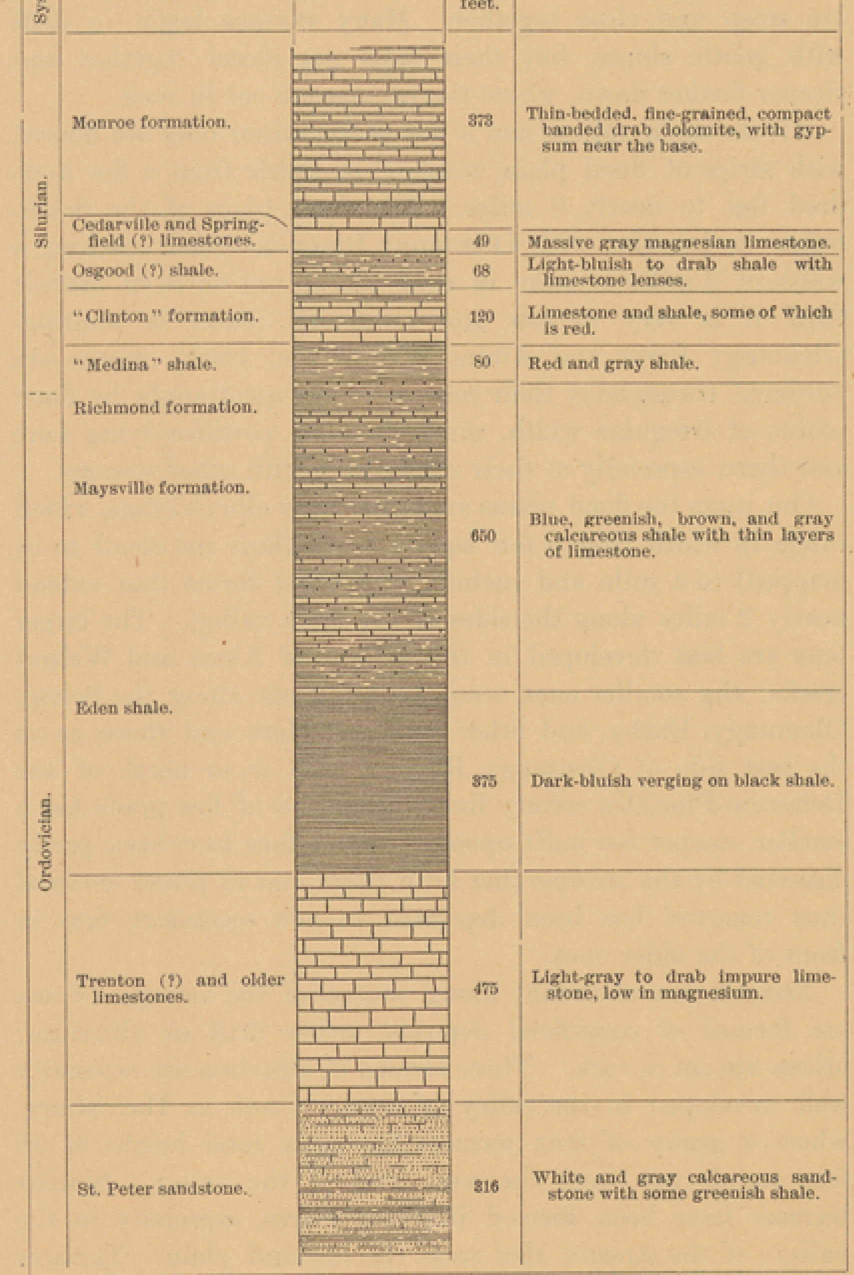

FIGURE 4.—Columnar section of the rocks encountered in drilling in the Columbus quadrangle.
Scale: 1 inch=400 feet.

In the Columbus quadrangle the St. Peter sandstone is overlain by 475 feet of light-gray to drab impure limestone, which has heretofore been referred to the Trenton limestone but is regarded by Ulrich as of Stones River and lower Mohawkian age. This limestone contains only a small amount of magnesium carbonate and is decidedly different in physical character and chemical composition from the rock that occupies the same stratigraphic position in the oil region in northwestern Ohio, which is a true dolomite. The chemical composition of the rock at Columbus is shown by the following analysis of a sample taken from one of the deep wells of the region:

Analysis of limestone from deep well near Columbus.

Calcium carbonate	69.3
Magnesium carbonate	4.3
Iron and aluminum oxides	2.7
Insoluble residue	23.6
	99.9

Above the limestone just described is a dark to almost black shale, reported in the Columbus quadrangle as 375 feet thick. It is thought to be the lower part of the Eden shale, which seems to be rather persistent throughout the State. The Eden shale is exposed in the valley of Ohio River at Cincinnati, where it consists of 250 feet of soft blue shale and a few thin interbedded layers of limestone.

In the Columbus quadrangle the dark shale is overlain by 650 feet of blue to greenish-brown and gray calcareous shale, which probably includes a considerable proportion of blue limestone, and which is largely referable to the Upper Ordovician. The lower part of these beds is probably upper Eden, the middle, the greatest part, presumably belongs in the Maysville formation of the Cincinnatian series, and the upper part is probably Richmond, but the records are so imperfect that the formations have not been separated. The exact boundary between the Ordovician and Silurian systems in central Ohio is a subject of controversy and one on which the well records furnish no direct evidence. In this folio, as in general practice, the beds correlated with the Richmond are assigned to the Ordovician.

SILURIAN SYSTEM.

The lowest formation referred to the Silurian consists of red and gray shale 80 feet thick, which doubtless represents a part of the Medina group.

The next overlying limestone and shale, which have a total thickness of 120 feet and include some red layers, are referred to the formation usually called the Clinton in Ohio. In the vicinity of Waynesville this formation is composed of white, pink, and red crinoidal limestone, which caps many of the hills and is believed by Ulrich and others to be older than the true Clinton.

About 68 feet of soft, light-bluish to drab shale, which is thought to be the Osgood shale, and which includes some thin calcareous layers, overlies the "Clinton" in central Ohio. In areas farther southwest the shale is thicker and is interbedded in part with the Dayton limestone. The Osgood is equivalent to the Rochester shale member of the Clinton formation of western New York and has been positively correlated with it by Bassler.

Above the supposed Osgood shale is 49 feet of limestone, which must include the Cedarville limestone and perhaps the underlying Springfield limestone, although the Springfield thins rapidly northeastward and may not extend to the Columbus quadrangle. Where the Cedarville limestone outcrops near Cedarville it is a massive gray dolomitic limestone with some thin-bedded layers and contains a typically Niagaran fauna, which exhibits close relations to that found in the equivalent beds in eastern Wisconsin.

ROCKS EXPOSED.

SILURIAN SYSTEM.

MONROE FORMATION.

Distribution, character, and thickness.—The lowest outcropping formation in the Columbus quadrangle is the Monroe, a fine-grained, compact, rather thin bedded, and generally distinctly banded drab dolomite. Wells at Columbus have penetrated 373 feet of such dolomite, which includes considerable gypsum and part of which probably represents the Salina formation of New York. The Monroe formation thickens materially toward the north, especially near Lake Erie.

The formation occupies a narrow, discontinuous strip along the western border of the quadrangle, where it occurs in small outcrops along Darby, Little Darby, and Mill creeks, which expose, as a rule, a thickness of 6 to 8 feet of the rocks. The contact between the formation and the overlying Columbus limestone is exposed along Darby Creek 3 miles northwest of Harrisburg and at many places farther north, although the outcrops are poor and of little interest except for the contact they show. Low outcrops of the Monroe skirt the banks of Mill Creek at many places for a distance of several miles north of Watkins, but they pass under drainage level at a cliff of

Columbus limestone west of Bellepoint. The best and most accessible outcrops of the formation, as well as of its upper contact, are in the vicinity of Georgesville. In the south bank

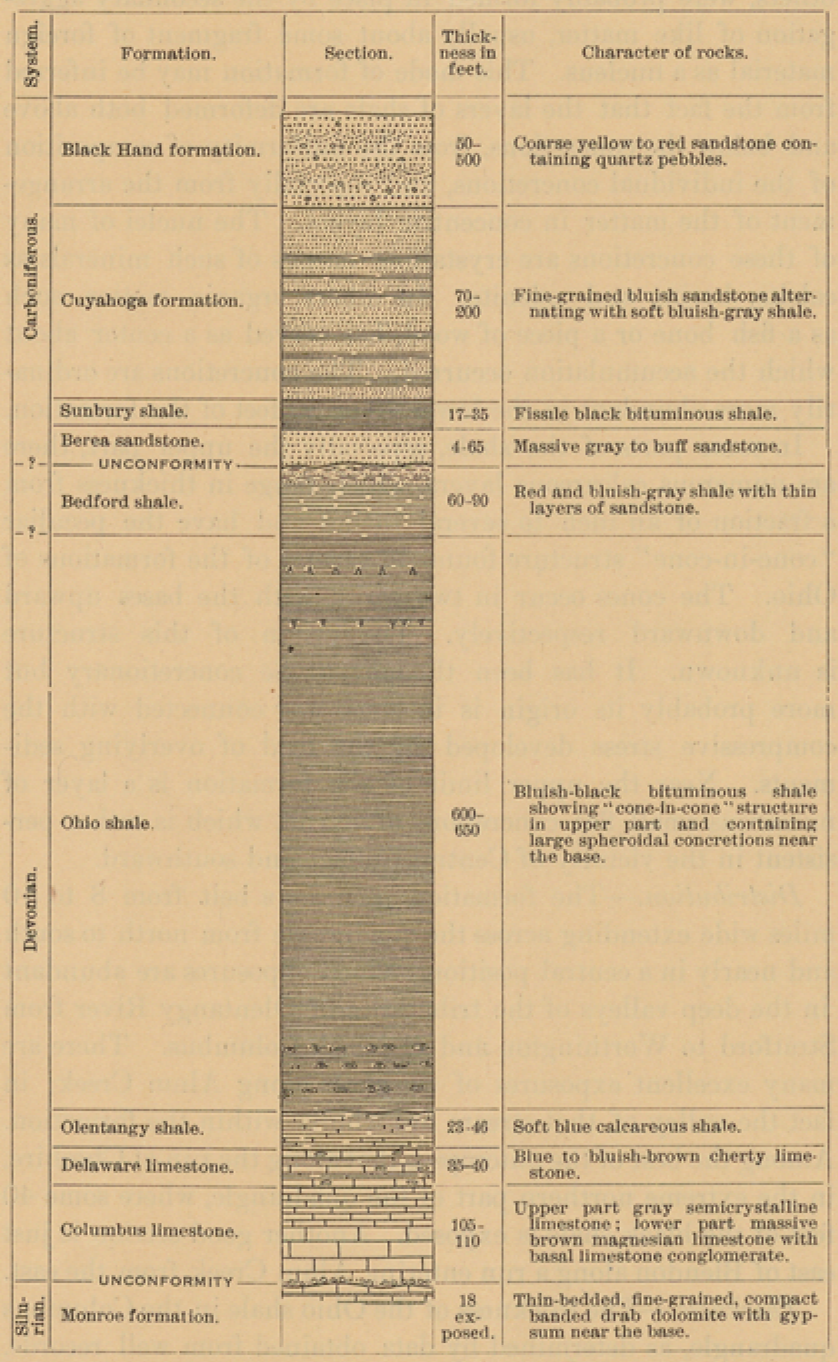

FIGURE 5.—Columnar section of the rocks exposed in the Columbus quadrangle.

Scale: 1 inch=200 feet.

of Little Darby Creek about a mile west of its junction with the Big Darby the following section is exposed in the limestone cliff:

Section in the cliff along Little Darby Creek near Georgesville.

	Ft.	in.
Columbus limestone:		
Limestone, rather massive, semicrystalline, brown, with pockets of calcite crystals; weathers irregularly with a conspicuously pitted or honeycombed surface and forms a red residual soil	12	5
Limestone, drab with a yellowish tinge, mottled with darker spots; commonly semicrystalline; occurs in a single layer with an uneven but not honeycombed surface	2	0
Unconformity.		
Monroe formation:		
Limestone, drab, thin, uneven bedded, very impure; contains some seams of calcite in the upper part; has rough bedding planes, is contorted, and weathers with a honeycombed surface	3	8
Limestone, very light colored, fine grained, compact, in three conspicuous layers, has a clean vertical fracture; more evenly bedded than the overlying bed	4	0
Limestone, massive; weathers into irregular layers with uneven bedding planes; lower layers compact and fine grained	4	0
Limestone, thin bedded, ash-colored, banded; breaks with a clean vertical fracture	1	0
Limestone, drab to yellowish, massive impure argillaceous, magnesian; exposed at intervals to low-water level	5	10

Fossils and correlation.—The fauna of this great mass of dolomite is small and rather poorly preserved. In the Columbus quadrangle *Leperditia altoides* and *Spirifer ohioensis* var. have been found, but even these are rare. In other regions, especially northern Ohio, southwestern Ontario, and southern Michigan, the Monroe contains a larger variety of forms. Many of them show marked Devonian affinities, so that the correlation of the beds has been questioned. As the term Monroe has usually been applied in Ohio it is not a formation but a group name, and has been employed to designate the Silurian strata lying above the strata of Niagaran age. It represents the period of geologic time during which much of the Cayuga group of New York was deposited.

DEVONIAN SYSTEM.

COLUMBUS LIMESTONE.

Character, thickness, and distribution.—Upon the Monroe formation lie unconformably calcareous and magnesian strata, 105 to 110 feet thick, which Newberry named the Columbus limestone, "as it is the rock opened in the quarries near that city."[1] The type locality is at the old State and Marble Cliff quarries along Scioto River. (See Pl. IV.) The lower 40 feet of the formation consists of brown magnesian limestone containing much bituminous matter and showing a wavy, banded structure, which is not nearly so pronounced as that of the Monroe formation. The beds are massive, irregular, and more or less indistinctly separated. They contain, here and there, small masses of chert and pockets of calcite crystals. As a rule the layers show little signs of crystallization, but some blocks glisten with calcite cleavage faces. The chemical composition of this part of the Columbus limestone is well shown by the following analysis of a sample taken at Dublin:[1]

Analysis of limestone from Dublin, Ohio.

Calcium carbonate	55.09
Magnesium carbonate	41.07
Iron oxide	.63
Siliceous matter	1.96
Organic matter	.92
	99.67

The lowermost layers are a true basal conglomerate, consisting of pebbles of compact banded drab limestone of the Monroe formation embedded in a matrix of brown Columbus limestone. The pebbles are well rounded and range in diameter from a fraction of an inch to 3 or 4 inches. In some places a little quartz sand is mingled with the pebbles, and at others the sand is so abundant that the rock has been called a sandstone. The thickness of the conglomerate is at most places about 6 inches and at very few is it more than 2 feet. It may be seen at nearly every exposure of the contact in the central part of the State and is well shown along Big Darby Creek about 2 miles above Georgesville.

The upper 65 feet of the formation consists of highly calcareous semicrystalline gray limestone, evenly bedded and very fossiliferous which are the quarry beds, shown in figure 9 (p. 13). The following analysis of a specimen from Marble Cliff[2] shows the chemical composition of this portion of the formation:

Analysis of specimen of Columbus limestone.

Calcium carbonate	93.28
Magnesium carbonate	2.69
Iron and aluminum oxides	2.18
Siliceous matter	1.41
	99.56

About 9 feet below the top of the formation is the "smooth rock," whose surface resembles well-developed slickensides, analogous to those found along many fault planes. Fossils lying along this surface are planed off smoothly. It seems probable that this is a plane along which motion has taken place between two layers of rock—a shear plane. It is most perfectly developed at Marble Cliff and at the State quarries, but may be traced northward at least as far as Dublin. In some places, as at Casparis quarry, the shearing, if such it be, occurred along two parallel planes about a foot apart; as a rule, however, there is but one plane. At Marble Cliff these smooth surfaces show distinct ripple marks and the smooth surface has been explained as due merely to the compacting of the calcareous muds under the action of the waves at a time when perhaps little sedimentation was taking place. It is doubtful, however, whether a surface so smooth could be so perfectly preserved in the soft calcareous muds. Moreover, the ripples are not sharp but more or less round crested, as they might be if a small amount of motion had taken place along the smooth surface.

The upper 6 to 8 inches of the formation is the "bone bed," which contains at many places abundant plates and teeth of fishes. "Here we have the assemblage of millions on millions of generally imperfect but mostly recognizable organs or fragments of the bony structure of the forms of fish life most characteristic of the Devonian age."[3] The bones and teeth are excellently preserved, retaining even their original luster. The "bone bed" is coextensive with the outcrops in the central part of the State and is well enough defined at Sandusky to be recognizable. An excellent outcrop of this layer occurs in the small run that enters Scioto River from the east at Fishinger's bridge, a mile above the Columbus storage dam.

Another important feature of the formation consists of the chert beds and their associated fauna, which is especially remarkable for its excellent preservation and for the great number of mollusks it includes. The more important chert zone is about 60 feet below the "bone bed" at the top of the formation. At the storage dam it is about 9 feet thick but thins out northward. The chert occurs mainly in concretionary masses, the silica of which was probably derived from scattered siliceous tests and spicules of plants and animals, and was subsequently aggregated, by ground water, into the form of cherty nodules, and by replacement it has changed many calcareous into siliceous fossils.

The formation occupies a belt from 2 to 6 miles wide along the west side of the quadrangle, a narrow strip extending down the valley of the Scioto from Bellepoint to Columbus, and two small areas along Olentangy River in Liberty Township. In the broad belt the limestone is rarely exposed naturally, although it is often struck in wells and sometimes uncovered in plowing or in digging trenches. It is well exposed along the Scioto above Columbus. The section in the quarries at Marble Cliff may be considered as typical of the upper part, whereas a little of the lower part is exposed just below the Columbus storage dam, and the entire thickness of the massive brown portion outcrops along the Scioto and its tributaries near Bellepoint.

The following section, which was measured at the Columbus storage dam during its construction and includes the quarry on the west bank, is one of the most complete ever obtained for these beds. The lower 35 feet of the measurement for the Columbus limestone and the whole of that given for the Monroe formation was taken from the core of one of the borings made in testing the solidity of the bedrock as foundation for the dam.

Section at Columbus storage dam.

	Ft.	in.
Delaware limestone:		
Limestone, bluish, with much black chert	1	6
Limestone, bluish brown, shaly, with bands of black chert	4	2
Shale, soft, thin bedded, brown, with some black chert	1	2
Columbus limestone:		
Limestone, rather massive, bluish gray, subcrystalline; some gray-white chert and a well-defined "bone bed" at top; *Eridophyllum verneuilianum*, *Spirifer acuminatus*, and *Platyceras dumosum* are characteristic fossils	9	6
Limestone, gray, very fossiliferous, and fairly massive, showing "smooth rock" at the top: characterized by large cephalopods among which *Ryticeras cyclops* is conspicuous	20	4
Limestone, massive, bluish gray, containing great numbers of *Spirifer gregarius;* the cavities in the rock and the interior of many of the fossils are filled with petroleum	5	0
Limestone, massive, gray, containing numerous corals and brachiopods	16	0
Limestone made up largely of *Favosites emmonsi*		6
Limestone, massive, gray, very fossiliferous; *Spirifer macrothyris* common	2	5
Limestone, grayish brown, cherty, especially rich in gastropods; *Bellerophon pelops*, *Loxonema pexatum*, *Hormotoma maia* common	9	4
Limestone, gray to brown, made up largely of corals belonging to the genera Favosites, Syringopora, and Synaptophyllum	3	6
Partly covered to level of the top of well No. 10	5	3
Limestone, strongly magnesian, massive, brown	31	10
Conglomerate, brown limestone, with embedded pebbles of banded drab dolomite	2	4
Monroe formation:		
Dolomite, drab, mostly thin bedded	7	0
Dolomite, drab to dark brown, massive to bottom of well	9	3

Fossils and correlation.—The Columbus limestone contains the usual Onondaga fauna in great abundance. Among its more common species are—

Calcisphæra robusta Williamson.
Eridophyllum verneuilianum Edwards and Haime.
Favosites emmonsi Rominger.
Favosites hemisphericus (Troost).
Favosites turbinatus Billings.
Heliophyllum corniculum (Lesueur).
Syringopora tabulata Edwards and Haime.
Zaphrentis gigantea Lesueur.
Zaphrentis prolifica Billings.
Stromatoporella granulata Nicholson.
Nucleocrinus verneuili (Troost).
Coscinium striatum Hall and Simpson.
Cystodictya gilberti (Meek).
Polypora celsipora (Hall).
Atrypa reticularis (Linnæus).
Camarotœchia tethys (Billings).
Chonetes mucronatus Hall.
Leptæna rhomboidalis (Wilckens).
Meristella nasuta (Conrad).
Pentamerella arata (Conrad).
Rhipidomella vanuxemi Hall.
Spirifer acuminatus (Conrad).
Spirifer gregarius Clapp.
Spirifer macrothyris Hall.
Stropheodonta demissa (Conrad).
Stropheodonta hemispherica Hall.
Stropheodonta perplana (Conrad).
Strophonella ampla Hall.
Aviculopecten princeps (Conrad).
Conocardium cuneus (Conrad).
Limopteria pauperata Hall.
Modiomorpha concentrica (Conrad).
Paracyclas elliptica Hall.
Bellerophon pelops Hall.
Callonema bellatulum (Hall).
Diaphorostoma lineatum (Conrad).
Euryzone lucina (Hall).
Hormotoma maia (Hall).
Loxonema pexatum Hall.
Platyceras dumosum Conrad.
Pleuronotus decewi (Billings).
Turbonopsis shumardi (De Verneuil).
Tentaculites scalariformis Hall.
Poterioceras eximium (Hall).
Ryticeras cyclops (Hall).
Spyroceras thoas (Hall).
Chasmops anchiops (Green).
Coronura diurus (Green).
Phacops cristata Hall.
Proetus rowi (Green).
Macropetalichthys rapheidolabis Norwood and Owen.

Any species characteristic of the Onondaga limestone is likely to be found in its Ohio equivalent.

Along Scioto River, especially on the west bank between the Casparis quarry and the old State quarries, there are many active quarries or abandoned pits in the Columbus limestone, in which the collector may find a wealth of fossils such as is exceeded at but few other localities. Unfortunately, however, the fossils are embedded in the solid limestone and are generally not easily extracted.

Fossils are rare in the lower part of the formation and those which are found are as a rule poorly preserved molds and casts. The scarcity of organic remains is probably due not to poverty of the fauna during the time of deposition of the sediment but to subsequent changes that have affected these layers. Chemically they are nearly true dolomite, and dolomitization like all metamorphic processes, may be fatal to the preservation of fossils.

DELAWARE LIMESTONE.

Character, thickness, and distribution. — Overlying the Columbus limestone is 35 to 40 feet of blue to bluish-brown cherty limestone and calcareous shale, which contrasts strongly with the more purely calcareous limestone of the upper part of

[1] Ohio Geol. Survey vol. 1, pt. 1. p. 143, 1873.

[1] Orton, Edward. Report on the geology of Franklin County: Ohio Geol. Survey, vol. 3, p. 616, 1878.
[2] Idem, p. 617.
[3] Newberry, J. S., U. S. Geol. Survey Mon. 16, p. 30, 1889.

the Columbus. This formation has received the name Delaware limestone. Its range in composition may be seen from the following analyses:[1]

Analyses of Delaware limestone.

	Shaly beds.	Building stone.
Calcium carbonate	72.82	57.09
Magnesium carbonate	5.99	33.14
Aluminum and iron oxides	2.80	2.97
Siliceous matter	16.06	5.33
Organic matter	1.75	.88
	99.42	99.41

The formation averages in thickness only about 36 feet in central Ohio, but is much thicker farther north, where it is also a purer limestone. At Delaware, from which city it takes its name, it has been extensively used as a building stone.

The formation occupies a belt from 2 to 6 miles wide extending from north to south across the quadrangle somewhat west of the middle, and a narrow strip in the valley of Olentangy River north of the boundary between Delaware and Franklin counties. For much of its length the broader belt is bisected by the narrow strip of Columbus limestone outcropping along Scioto River. South of Columbus the formation is covered by a rather thick deposit of drift, although it has been struck by the drill in sinking wells, and as a surface rock it appears to lie entirely west of the Scioto. Nearly every outcrop along that river within the quadrangle shows at least some of the Delaware. An excellent section is exposed along the Dublin pike on the east side of the river just beyond Fishinger's bridge, or 1½ miles above the Columbus storage dam, and the entire formation outcrops along Slate Run, not far beyond. Another section, which is equally interesting and which shows the overlying Olentangy shale somewhat better, is to be found along Bartholomew Run, which heads near Powell and enters Olentangy River a mile north of the Franklin-Delaware county line. The following section was measured along this run:

Section of Olentangy shale and Delaware limestone on Bartholomew Run.

	Ft.	in.
Ohio shale:		
Shale, black, rather thin bedded and considerably weathered, containing a number of large spheroidal concretions	16	0
Olentangy shale:		
Shale, soft, blue, marly; upper part yellowish	3	10
Layer of flat more or less disklike calcareous concretions		7
Shale, soft, blue, marly, with some brown layers	7	2
Limestone, impure, bluish		6
Shale, bluish, marly, with some thin bands of brown or black shale	2	0
Shale, black, containing some fragments of fossil plants		7
Shale, blue, marly	1	0
Shale, black; cut into small blocks by two very regular systems of joints; abundant pyrite		3
Shale, blue, marly	1	8
Limestone, impure, blue; in two distinct layers		4
Shale, bluish green, marly, containing bands of brown shale	2	4
Shale, brown, with bluish marl-filled marks or trails of marine "worms" and fragments of plants		3
Shale, soft, bluish green, marly, containing great numbers of small limestone concretions	5	0
Shale, brown, with some "worm" trails through it and containing a few bryozoans		3
Shale, bluish green, soft, and gritless, showing some trails of marine animals	2	4
Delaware limestone:		
Limestone, shaly, blue to brown, the top penetrated by "worm" holes and filled with blue marl from above; fish teeth and bones, somewhat waterworn, and a few pebbles are also included in the shaly mass; only known exposure of this contact		5
Limestone, very cherty, bluish brown; layers rather even and sparingly fossiliferous; called Tully limestone by Winchell and conceded by Newberry to contain a Hamilton fauna	9	4
Limestone, granular, grayish brown, containing much pyrite which has replaced the original substance of some of the fossils; carries a fauna containing the small globular coral, *Hadrophyllum d'orbignyi*		8
Limestone, massive, bluish; containing very little chert	2	0
Limestone, thin bedded, shaly, with much black chert	1	0
Limestone, blue to brown, containing pyrite and black chert intermingled and much contorted; these layers, together with the two just above, generally contain many specimens of *Grammysia bisulcata*	4	0
Limestone, rather massive blue, with some chert and shaly layers; *Tentaculites scalariformis* abundant	8	0
Shale, thin bedded, brown, calcareous, with thin layers of black chert; contains the Marcellus shale fauna	7	0
Limestone, brown, somewhat shaly; probably a part of the above zone, extending to level of the run below the highway bridge	2	6

Fossils and correlation.—The Delaware limestone is not so fossiliferous as the Columbus, but it includes many layers that are crowded with organic remains. Its fauna is made up in part of forms surviving from Onondaga time and in part of Hamilton forms. Among the more characteristic species are the following:

[1] Ohio Geol. Survey, vol. 3, p. 618, 1878.

Cystiphyllum vesiculosum Goldfuss.
Hadrophyllum d'orbignyi Edwards and Haime.
Heliophyllum halli Edwards and Haime.
Cystodictya hamiltonensis Ulrich.
Ambocœlia umbonata (Conrad).
Camarotœchia prolifica Hall.
Chonetes deflectus Hall.
Cyrtina hamiltonensis Hall.
Delthyris consobrina (D'Orbigny).
Leiorhynchus limitare (Vanuxem).
Leptæna rhomboidalis (Wilckens).
Lingula ligea Hall.
Lingula manni Hall.
Martinia maia (Billings).
Orbiculoidea lodiensis (Vanuxem).
Pholidostrophia iowaensis (Owen).
Rhipidomella vanuxemi Hall.
Spirifer audaculus (Conrad).
Stropheodonta concava Hall.
Stropheodonta demissa (Conrad).
Stropheodonta perplana (Conrad).
Aviculopecten princeps (Conrad).
Cypricardella tenuistriata (Hall).
Actinodesma erectum (Conrad).
Grammysia bisulcata (Conrad).
Nyassa arguta Hall.
Sphenotus cuneatus (Conrad).
Platyceras erectum (Hall).
Tentaculites scalariformis Hall.
Phacops rana (Green).

The lowermost 5 to 10 feet of the formation consists of brown shale in which Whitfield discovered a fauna that led him to correlate it with the Marcellus shale of New York. These Marcellus fossils may be found in nearly every outcrop of this shale in the quadrangle.

As a whole the fauna of the Delaware limestone is intimately related to that of the Traverse formation of Michigan and of the basal part of the Hamilton formation of New York, although in central Ohio it still retains certain forms that are found also in the Onondaga fauna. The latter, however, are chiefly forms that have a long range in geologic time and that are therefore of little value for determining correlations. A few species, however, which were formerly thought to be characteristic of the Onondaga are found in the Delaware limestone. Although the Delaware is unquestionably of Marcellus and basal Hamilton age, it is certain that the conditions under which it was deposited resembled somewhat more those that prevailed during the development of the Columbus limestone. Persistent Onondaga species are therefore more abundant among these calcareous sediments of Ohio than in the bituminous and argillaceous shale in New York.

OLENTANGY SHALE.

Character and thickness.—Upon the Delaware limestone lies from 23 to 46 feet of soft blue calcareous and argillaceous shale, with several persistent thin layers of argillaceous limestone, constituting the Olentangy shale. Several layers of black shale similar to the Ohio shale, and several more or less well-defined beds of flat calcareous concretions are interbedded with the soft blue layers. Notwithstanding the transitional character of the formation, however, its contacts with the underlying Delaware limestone and the overlying Ohio shale are at many places sharply defined. At some places the black shale lies on a decidedly uneven surface, as at Dripping Rock and at the type section along Olentangy River at Delaware. The section along Bartholomew Run, given above, shows well the general makeup of the formation.

Distribution.—The formation occupies a narrow strip, generally less than half a mile wide, extending from north to south across the middle of the quadrangle, and an irregular area in the valley of Olentangy River, extending southward to the Delaware-Franklin county line. The exposures are confined to the valley of Olentangy River and to the ravine of Slate Run.

Fossils and correlation.—The formation contains very few fossils. The only traces of animal remains found in it within the quadrangle are a few fish teeth, a crinoid stem, one pelecypod shell, and a bryozoan. In several layers of brown to purplish-blue shale occurring persistently in the lower part of the formation there are markings which seem to be worm trails. The usual assignment of a Hamilton age to the Olentangy is undoubtedly correct. Its lithologic character and the meager fauna found in the outcrops just north of the Columbus quadrangle both lend support to that assignment. It is reasonably certain that the limestone and marl of Prout, Ohio, which have yielded a fauna of lower Hamilton age, form the northern equivalent of the Olentangy shale. The basis for this belief rests on the similarity of the fossils found in the Olentangy shale at Delaware and in the marl at Prout, near Sandusky.

OHIO SHALE.

Characteristic features.—The Ohio shale, which overlies the Olentangy shale, is generally bluish-black or brown in fresh exposures, but in places it is composed partly of bluish-gray layers. Weathered surfaces may be distinctly blue, but in many places they retain their characteristic black color, except for iron stains that give them a dull-brown hue. The shale is firm and somewhat massive when first exposed, but it is soon broken up into more or less thin laminæ which later break into small fissile fragments, and in the end it weathers to a rather stiff clay. It contains a considerable amount of pyrite, which gives the dull brown of the weathered surface above referred to. The shale exhibits two more or less regular systems of joints which, along Rocky Fork, trend approximately N. 45° E. and N. 45° W.

A characteristic feature of the lower part of the formation is the occurrence of large "ironstone" concretions at several horizons. (See Pl. VI.) They ordinarily measure from 1½ inches to 3 feet in diameter but some are as much as 6 feet across. Most of them are spheroidal but some are of other forms. In places the bedding planes may be traced into the concretions, showing that at least part of the original shale is included within the mass. These concretions, like most others, were probably formed in place by the secondary aggregation of like matter, usually about some fragment of foreign material as a nucleus. This mode of formation may be inferred from the fact that the layers of shale are deformed both above and below the concretions, from the uniformity of composition of the individual concretions, and especially from the arrangement of the matter in concentric layers. The nuclei of many of these concretions are crystalline masses of such minerals as calcite, barite, and selenite. In others organic matter, such as a fish bone or a piece of wood, has served as a center about which the accumulation occurred. The concretions are ordinarily more abundant in the lower 40 or 50 feet of the formation.

In some parts of the shale, especially the upper part, there are numerous calcareous layers, which range in thickness from a fraction of an inch to several inches and have the peculiar "cone-in-cone" structure found in several of the formations of Ohio. The cones occur in two series, with the bases upward and downward respectively. The origin of this structure is unknown. It has been thought to be concretionary but more probably its origin is in some way connected with the compressive stress developed by the load of overlying sediments. Near the upper limit of the formation is a layer of numerous small flat concretions of pyrite, which is rather persistent in the vicinity of Central College and southward.

Distribution.—The formation occupies a belt from 8 to 10 miles wide extending across the quadrangle from north to south and nearly in a central position. Good exposures are abundant in the deep valleys of the tributaries of Olentangy River from Stratford to Worthington and at North Columbus. There are many excellent exposures of the shale along Alum Creek; in fact the valley of that stream lies wholly within the formation. Among the best of the outcrops is that along the run at Cheshire, in the extreme northern part of the quadrangle, where some 40 feet of the black shale is exposed. Another good section is just east of Blendon along a run entering Alum Creek from the east.

Thickness.—The thickness of the Ohio shale in the Columbus quadrangle, as determined by data obtained from well records, is between 600 and 650 feet.

The following section, measured along Lewis Center Run, includes rather more of the Ohio shale than that along Bartholomew Run; it also shows something of the formation:

Section of Devonian shales and limestone along Lewis Center Run.

	Ft.	in.
Ohio shale:		
Shale, black, well jointed, with some spheroidal concretions and other small ones of pyrite; contains some fragmentary fossil plants	35	0
Shale, soft, gray, with black layers in upper part	10	0
Shale, black, with spheroidal concretions	25	0
	70	0
Olentangy shale:		
Shale, soft, blue, marly	3	4
Layer of argillaceous blue limestone concretions, more or less discoidal		7
Shale, soft, greenish blue, marly	3	2
Layer of irregular flat limestone concretions with much pyrite		3
Shale, soft, bluish green	3	
Limestone, argillaceous, same color as shale		5
Shale, soft, greenish blue, with some layers of brown to black shale	16	0
Layer of irregular flat bluish limestone concretions		7
Shale, soft, greenish blue, marly	1	6
Layer of irregular flat limestone concretions		4
Shale, bluish green	2	0
Limestone, blue		6
Shale, soft, greenish blue, partly covered	8	0
	39	8
Delaware limestone:		
Limestone, bluish brown, rather massive, not abundantly fossiliferous	9	0
Limestone, gray, slightly granular, containing *Hadrophyllum d'orbignyi*		2
Limestone, bluish brown, fossiliferous		10
Limestone, bluish, granular, crinoidal, with some fossiliferous gray chert; corals abundant	1	3
Limestone, brown, and chert, black, much intermixed and contorted	3	0
Limestone, bluish, alternating with black chert	4	0
Limestone, bluish, massive, and fossiliferous, to level of Olentangy River	5	4
	23	7

Fossils.—Aside from the rather rare impressions of long flattened stems (Calamites), leaves, and spore cases of plants, the fossil wood associated with some concretions, a Lingula, conodont teeth, and a few fish bones, the great body of the formation is practically barren of fossils in the Columbus region. In the uppermost layers, however, certain forms which seem to belong to the Bedford fauna appear in the black shale, as if this fauna had appeared before the close of the period in which the conditions favored the formation of black shale. Perhaps, however, the sea in which the Bedford was deposited worked over some of the black mud of the Ohio shale and the true boundary between the two formations lies below the fauna.

Divisions and correlation.—In the northern part of the State the Ohio shale becomes a group, composed of three more or less distinct formations—the Huron shale, the Chagrin formation, and the Cleveland shale. However, Dr. Prosser regards the Huron shale as "the western lithologically more or less changed stratigraphic equivalent of the Chagrin formation."[1] The propriety of this correlation, however, is not admitted by some geologists. The threefold division indicated above has not been applied to this formation in central Ohio, nor is it clear that the separate formations would be recognizable there, yet it is interesting to note that the middle part of the formation in the Columbus region contains numerous layers of soft bluish-gray shale resembling somewhat that of the same horizon, the Chagrin, farther north. The Cleveland shale probably does reach the Columbus region and may be represented by the greater part of the Ohio shale, but up to the present time no satisfactory dividing line has been discovered between it and the remainder of the Ohio shale beneath it.

The Ohio shale is equivalent, in whole or in part, to the Antrim shale of Michigan, the black New Albany shale of Indiana, and the Chattanooga shale of the southern Appalachian Valley, which are sometimes referred to as of Genesee age. In the opinion of most geologists, however, these formations represent the sediment accumulated in this part of the sea while the Genesee, Portage, and Chemung strata were being deposited in New York. The view has been advanced by Ulrich that the Ohio shale and its representatives toward the south are of Mississippian age.

DEVONIAN OR CARBONIFEROUS SYSTEM.

BEDFORD SHALE.

Character, distribution, and thickness.—The Bedford consists of clay shale and, near the top, of some thin layers of sandstone. It ranges in color from bluish gray to red or chocolate-brown, the red being seen mainly in the middle part of the formation. In fresh outcrops, as in stream beds, the strata appear massive, but on exposure they soon weather to a sticky red or yellow clay. The formation in weathered condition is well exposed in the hills east of Central College, where it forms a line of bluffs along the east bank of Big Walnut Creek. The soft and easily eroded shale has been carved into striking forms resembling, to some extent, those of the badlands of South Dakota and Nebraska. The color of the middle part of the formation is so conspicuous that the name Red Hills has been given to the locality.

The lower part of the formation, especially in the eastern part of the quadrangle, includes several layers of small, flat argillaceous concretions, which have a decidedly concentric structure and some of which contain fossils. Near Lithopolis much larger concretions of irregular shape are often found.

One of the most notable features of the formation in this part of the State, as well as in the vicinity of Cleveland, is the disturbed condition of the strata in the upper part. Many of the beds are much contorted, and in places even crushed, whereas the overlying Berea sandstone is little or not at all so affected. The nature of the material of the Bedford shale indicates that it was deposited at some distance from shore. Perhaps at the outer margin of this mud deposit, or even elsewhere, there were steep submarine slopes. The slumping or superficial faulting of such deposits would result in the contortion of the layers, especially if the material were sufficiently tenacious to hold together.

The thickness of the Bedford shale ranges from 60 feet in the northern part to 90 feet in the southern part of the Columbus quadrangle. Its base is ordinarily defined by a highly fossiliferous bed, but at many places it is not easily distinguished from the overlying Berea sandstone, for the upper part of the Bedford is commonly arenaceous. Dr. Prosser, however, regards the greater percentage of calcium carbonate in the Bedford as a means of distinguishing it from the Berea where the two are physically similar. Toward the top of the formation thin sandstone layers are progressively more numerous until they make the whole bulk of the rock. Moreover, these thin layers of sandstone bear ripple marks, which indicate that they were formed near a shore under conditions similar to those under which at least a large part of the rock usually included in the Berea was deposited. This transition is especially well displayed along Big Walnut Creek between Galena and Sunbury. Along Rattlesnake Creek, however, near its junction with Big Walnut Creek, a massive concretionary layer marks the real beginning of the sandstone and hence the probable base of the Berea. Somewhat similar conditions exist along Rocky Fork, near Gahanna, but at other places, even in the northern part of the quadrangle, the Berea is markedly unconformable on the Bedford.[2]

The formation occupies an irregular narrow belt extending from north to south across the eastern part of the quadrangle. It outcrops chiefly along the east bank of Big Walnut Creek, except south of the National Road, where it swings eastward and is exposed chiefly along Black Lick and the tributaries of Little Walnut Creek.

Numerous outcrops furnish good sections of the formation. The sections given are selected because they are fairly accessible and because they show some of the succeeding formations excellently. The following is a combined section of the outcrops occurring along Rocky Fork from its union with Walnut Creek below Gahanna to the upper part of its tributary that flows through New Albany.

Section of Bedford shale and associated formations along Rocky Fork.

	Ft.	in.
Cuyahoga formation:		
Sandstone, thin bedded, alternating with bluish shale; exposed along the tributary of Rocky Fork flowing through New Albany	50	0
Shale, soft bluish	5	0
	55	0
Sunbury shale:		
Covered interval, most of it probably belonging to the Sunbury shale	10	0
Shale, fissile, black, iron stained, and somewhat decomposed; the lower 2 or 3 inches containing abundant brachiopods and some fish teeth; exposed along a small tributary at the bend of Rocky Fork just south of highway	25	8
	35	8
Berea sandstone:		
Sandstone, rather massive, many lenticular beds and some showing ripple marks; layer of marcasite on top	17	6
Sandstone, fine grained, in layers from a fraction of an inch to 10 inches thick and well ripple marked; some layers much contorted in places and with local beds of shale	8	6
Shale, arenaceous, gray, grading into sandstone upstream and containing some thin layers of ripple-marked sandstone	12	0
Sandstone, concretionary	1	0
	39	0
Bedford shale:		
Shale, soft, argillaceous, blue, arenaceous toward top; some slablike fragments when freshly exposed show marks resembling the impressions of plant stems	38	8
Shale, soft, argillaceous, gray, mottled	8	0
Shale, soft, fissile, chocolate-brown; weathers rapidly to stiff reddish clay	25	6
Shale, soft, argillaceous, blue; fissile and much jointed	15	6
Shale, argillaceous, blue; very fossiliferous, especially near base	2	0
Shale, dark bluish brown, rather soft, containing some fossil shells and worm trails (?) cast in pyrite		4
	90	0
Ohio shale:		
Shale, black, prominently jointed (joints running northeast and northwest), and much iron stained	5	0
Covered interval	5	0
Shale, black	10	8
Shale, black, with several layers of "cone-in-cone," to level of Big Walnut Creek	8	10
	29	6

The formation is well exposed at Taylor, on the Pennsylvania and Baltimore & Ohio railroads, where it is used in the manufacture of brick and tile. The contact with the Ohio shale is also exposed in the small gully at the north end of the brick and tile yards. Along Duncan Run there is an exceptionally fine section through the lower part of the Mississippian series and a part of the Devonian system. The following section gives the gross measurements taken in the cut made by this run:

Section of Bedford shale and associated formations along Duncan Run.

	Ft.	in.
Cuyahoga formation:		
Sandstone, blue to gray, in beds from a few inches to 6 or 8 inches thick	5	0
Shale, bluish gray, alternating with shaly sandstone, the surface showing marks resembling impressions of plant stems or trails of animals	10	0
Shale, gray, not well exposed	5	0
	20	0
Sunbury shale: Shale, fissile, black	30	0
Berea sandstone: Sandstone, buff to bluish gray, fine grained; upper layer much iron-stained, lower layers rather thin, shaly, and well ripple-marked	40	0
Bedford shale:		
Shale, mottled and gray, argillaceous with some sandy layers	28	6
Shale, soft; red or chocolate-brown	16	0
Shale, gray, with a few thin chocolate-brown layers	12	4
Shale, very compact, hard; red or chocolate-brown		4
Shale, soft, gray, argillaceous, containing fossils in the lower part	2	10
	60	0
Ohio shale: Shale, firm, black, to level of Big Walnut Creek	55	0

Fossils and correlation.—The greater part of the Bedford shale is unfossiliferous. In most places, however, an abundant fauna occurs in a basal bed 1 foot to 2 feet thick. This fauna has never been carefully studied and many of its species still remain undescribed. The following list gives the genera, a few of the species, and some of the related forms in this fauna as it occurs along Rocky Fork:

Ambocœlia norwoodi Foerste.
Camarotœchia kentuckiensis Foerste.
Chonetes sp.
Cranæna sp.
Lingula meeki Herrick?
Lingula sp.
Nucleospira cf. minima Weller.
Orbiculoidea newberryi Hall
Productella cf. concentrica Hall.
Rhipidomella cf. missouriensis Swallow.
Schuchertella herricki Foerste.
Syringothyris carteri Hall.
Macrodon irvinensis Foerste.
Microdon cf. reservatus Hall.
Microdon sp.
Nucula cf. glenparkensis Weller.
Nuculana sp.
Palæoneilo bedfordensis Meek.
Pterinopecten sp.
Sphenotus sp.
Bellerophon cf. jeffersonensis Weller.
Bellerophon sp.
Bembexia sp.
Pleurotomaria sp.
Conularia sp.
Goniatites sp.
Orthoceras sp.

This fauna is no less remarkable in its association of species than in its occurrence among essentially barren deposits. Although it contains a Devonian element, which links it in a general way to the Hamilton, it also resembles certain faunas of the Kinderhook, such as that of the Glen Park limestone member, so far as they contain a Hamilton element. However, the Bedford fauna differs widely from the normal northern faunas of the Kinderhook. Besides the unconformity at the top there is faunal evidence of the Devonian age of the Bedford, notwithstanding the fact that its fauna resembles that of the Hamilton rather than that of the Chemung, although stratigraphically it lies above the probable representative of the Chemung. Evidence that the Bedford shale is Devonian has recently been presented by Girty,[1] Prosser,[2] and Kindle.[3] It must be borne in mind, however, that this recurrent Devonian element is found elsewhere in the Mississippian of Ohio and that it may be traced in various faunules through the Cuyahoga formation. A similar lingering of Devonian faunal elements in the Carboniferous beds of the southwest has been observed at many places. There is thus some evidence of the Carboniferous age of the Bedford fauna, which appears to be related especially to that of the early part of the southern Kinderhook. In view of the inconclusive evidence regarding its age or relations, the correlation of the Bedford fauna is much in doubt.

CARBONIFEROUS SYSTEM.

MISSISSIPPIAN SERIES.

BEREA SANDSTONE.

Character, thickness, and distribution.—The Berea is the oldest persistent sandstone formation that outcrops in central Ohio. It is a rather medium grained gray to buff-colored rock and occurs in beds that are of various thicknesses but that are in general thicker or more massive toward the top of the formation. Some of the beds have a tendency to increase or decrease in thickness along their outcrops. (See Pl. V.) Distortion and concretionary structure are common throughout the lower part of the formation, and many of the beds so characterized grade into the ordinary layers. The thin layers and many of the thicker layers are notably ripple marked. Some of the ripple-marked beds are also contorted, so that the distortion occurred after the deposition and was not contemporaneous with it. A persistent and noteworthy feature of the formation is the occurrence of a layer of marcasite on its extreme upper surface. The decomposition of this iron sulphide probably gives rise to the hydrogen sulphide of the sulphur springs along Rocky Fork.

The thickness of the Berea is far from uniform. It is only 4 feet in the southeastern part of the quadrangle and Dr. Prosser finds it reduced to 13½ inches near Marcy, but it is probably more than 65 feet at Sunbury. This great difference may be in part due to the fact that at the locality last named, as at most others in central Ohio, it is almost impossible to draw the boundary line between the sandy upper layers of the Bedford shale and the succeeding Berea sandstone. In the southern part of the quadrangle, near Lithopolis, however, the Berea sandstone lies unconformably on the soft Bedford shale. (See Pl. V.)

The formation takes its name from Berea, Cuyahoga County, where it is extensively quarried. In southeastern Ohio it is one of the horizons at which oil and gas are found.

The formation occupies an irregular belt, from a quarter of a mile to 3 miles wide, extending southward from Sunbury across the eastern part of the quadrangle. Between Pickerington and Jefferson it reaches the eastern margin of the area. It is well exposed in the sections given in the description of the Bedford shale. In the following section, which was measured along Rattlesnake Creek opposite Sunbury, a greater thickness of the rock is exposed:

Section of Berea sandstone and associated formations along Rattlesnake Creek.

	Ft.	in.
Cuyahoga formation: Shale, soft, blue	5	0
Sunbury shale:		
Shale, black, bituminous; somewhat iron stained in meager outcrop	12	0
Shale, black, in partly covered interval	5	0
	17	0
Berea sandstone:		
Sandstone, gray to buff, rather thin bedded, with much iron sulphide in upper 4 inches	25	0
Sandstone in fairly thick lenticular layers interbedded with thin layers	15	0
Sandstone in concretionary masses with thin shaly layers, all more or less disturbed	5	6
Sandstone in ripple-marked thin shaly layers, somewhat banded	5	0
Sandstone in rather massive, somewhat concretionary layers interbedded with some shale	5	0
Shale, soft, arenaceous, containing some concretions	6	8
Layer of massive concretions, more or less continuous but interrupted and apparently somewhat replaced by bluish shale	3	0
	65	2
Bedford shale:		
Shale, bluish gray, rather argillaceous, but gritty	2	0
Covered to level of Big Walnut Creek	5	0
	7	0

[1] Prosser, C. S., Jour. Geology, vol. 21, p. 362, 1913.
[2] Idem, vol. 20, pp. 558-589, 1912.

[1] Girty, G. H., Geologic age of the Bedford shale of Ohio: New York Acad. Sci. Annals, vol. 21, pp. 295-319, 1912.
[2] Prosser, C. S., The Huron and Cleveland shales of northern Ohio: Jour. Geology, vol. 21, pp. 323-362, 1913.
[3] Kindle, E. M., The stratigraphic relations of the Devonian shales of northern Ohio: Am. Jour. Sci., 4th ser., vol. 34, pp. 212-213, 1914.

Fossils and correlation.—Fossils are rare in the Berea, none having been found in the Columbus region. In the northern part of the State, however, a few fossil fishes, probably fresh-water forms, have been found in it. At the village of Berea Dr. Newberry found in it also some shark teeth and a large Lingula, both of which indicate marine deposition. Fragments of wood resembling charcoal are abundant in the upper layers of the formation throughout the northern part of the State, where the deposit is probably in part a land formation. The "Corry" sandstone, which is the representative of the Berea sandstone, found in northwestern Pennsylvania, contains a considerable marine fauna, which has a distinctly Kinderhook facies.

SUNBURY SHALE.

Character and thickness.—Few sedimentary contacts are more clearly marked than that between the Berea sandstone and the Sunbury shale. The contact may be located within a fraction of an inch, the cessation of the deposition of sandy sediments having been very abrupt.

The Sunbury consists of 17 to 35 feet of black argillaceous shale containing much bituminous matter. It resembles somewhat in general appearance the Ohio shale but it is thinner bedded, more fissile, and less resistant to weathering. The lower layers of the shale, however, which cling with wonderful tenacity to the top of the Berea sandstone, are more resistant, and throughout large areas the Sunbury is represented by only a few inches of black shale overlying the sandstone.

The formation occupies an irregular belt, in places 2 miles across, extending from Sunbury southeastward across the eastern part of the quadrangle to Pickerington. It outcrops also in the southeastern part of the quadrangle, in a narrow sinuous belt that extends along the north and west margins of the group of hills around Chestnut Ridge. The type locality of the formation is along Rattlesnake Creek east of Sunbury, but it is better exposed along Rocky Fork northeast of Gahanna and in Dutch Hollow at Lithopolis. Some sections that include it have already been given, and a section at Dutch Hollow in which it is found is presented below, in the description of the Cuyahoga formation.

Fossils.—At many places the lower 6 or 8 inches of the formation is highly fossiliferous, although the number of species is small. *Lingula melie* Hall and *Orbiculoidea herzeri* Hall and Clarke are abundant, as are also fish teeth. The great body of the shale, however, is essentially nonfossiliferous.

CUYAHOGA FORMATION.

Character, thickness, and distribution.—In all sections that expose the contact between the Sunbury shale and the Cuyahoga formation the base of the Cuyahoga consists of 5 feet of bluish-gray shale. This shale is overlain by beds of fine-grained sandstone alternating with shale, chiefly of bluish color. Several persistent layers of the sandstone that occur in the southern part of the State were long ago designated by distinctive names, as Buena Vista stone and City Ledge. Dr. Prosser has revived the name Buena Vista and applied it to its possible equivalent in central Ohio. He calls the lower 50 feet of the Cuyahoga formation the Buena Vista member and says that the lowest sandstone of the member apparently corresponds to the stratum in southern Ohio termed the "City Ledge." Only a small part of the formation is exposed at any place within the quadrangle. Its character is well shown in Plate VII. Its total thickness, however, is about 200 feet at Chestnut Ridge.

The formation occupies the northeastern part of the quadrangle as far south as Pickerington and an area in the southeastern part on the slopes surrounding Chestnut Ridge.

The following section was measured along the little run in Dutch Hollow at Lithopolis. It begins near the 800-foot level, three-quarters of a mile northwest of the covered bridge and extends nearly a mile upstream.

Section of Cuyahoga and underlying formations in Dutch Hollow.

	Ft.	in.
Cuyahoga formation:		
Several fairly even compact layers of grayish sandstone, followed, in ascending order, by bands of arenaceous gray shale and soft uneven sandstone layers, to the crest of the hill at the Lyndecker quarry; the layers of shale contain fragments of plants	31	0
Freestone, compact, even grained, blue	4	0
Sandstone, interbedded with shale and thin shaly sandstone, outcropping at the covered bridge and along the steep bank below	31	0
Sandstone, blue but iron stained, in a massive layer	2	0
Shale, arenaceous, gray, and sandstone, blue in thin layers	4	2
Sandstone, blue, iron stained, in a massive layer; the "City Ledge"	2	9
Shale, very soft, gray; constitutes base of the formation wherever this part has been found outcropping	5	0
	79	11
Sunbury shale: Shale, fissile, black, in very thin laminæ and considerably iron stained in old exposures; containing *Lingula melie* and *Orbiculoidea herzeri* at base	21	0

	Ft.	in.
Berea sandstone: Sandstone, fairly coarse grained, gray, in thick, compact layers with no intercalated shale; upper part of exposure strongly impregnated with pyrite in small nodules or concretions; ripple marked	5	0
Bedford shale: Shale, soft, argillaceous, drab, but stained yellow where weathered	3	6

Fossils.—The shale of the Cuyahoga formation contains, besides abundant flat iron stone concretions, a few other concretions in which fossils have been found. Other than fragments of plants, no fossils were found in this shale in the Columbus quadrangle, although at some localities, especially in the northern and southern parts of the State, considerable collections of animal remains have been made at different horizons in the formation. Some of these faunules bear a marked resemblance to that found in the basal layers of the Bedford shale.

BLACK HAND FORMATION.

Character, thickness, and distribution.—The Black Hand formation consists of 50 to 500 feet of soft and hard coarse-grained sandstone ranging in color from yellow and buff to brown and red. Much of it is cross-bedded and in places it is very massive. Here and there the rock contains a number of quartz pebbles and in places approaches a true conglomerate. Only a small part of the formation outcrops in the quadrangle.

The formation occupies a small area in the southeast corner of the quadrangle, in the hilly region about Chestnut Ridge, southeast of Lithopolis. Chestnut Ridge is composed of a coarse, massive yellow sandstone, the base of the formation, which is extensively developed in Hocking Valley, 10 miles to the east. The hills are therefore geologically and topographically the outliers of the picturesquely eroded region that gives to Hocking Valley its beautiful scenery, and they owe their existence to the formation that caps them, which offers great resistance to weathering and erosion.

At the north end of Chestnut Ridge the upper shale and thin sandstones of the Cuyahoga formation are exposed to a point within 40 or 50 feet of the coarse yellow sandstone capping the ridge. A section at this point is given below.

Section of Black Hand and Cuyahoga formations at north end of Chestnut Ridge.

	Feet.
Black Hand formation:	
Sandstone, massive, thick bedded, coarse grained, soft, yellow; the whole rock is here and there impregnated with iron in irregular bands and concretions; at some places the layers are of various shades of red or brown, but at others the bands are entirely without coloring matter	40
Covered interval	50
	90
Cuyahoga formation:	
Sandstone, thin bedded, and shale, bluish, at the base of the exposure, more iron stained and somewhat coarser toward the top	60
Covered to road level at Jefferson	5
	65

Fossils and correlation.—At some places the formation contains fossils, but none were found in the region here considered. The sandstone of Chestnut Ridge resembles closely that seen in the quarries south of Newark and about Lancaster, but perhaps is more nearly like the rock near Lancaster, which is not so fine grained as that near Newark. This coarse sandstone can be traced almost continuously eastward to the vicinity of Lancaster, where it is well exposed in the westernmost outcrop of the formation at that place.

QUATERNARY SYSTEM.

GENERAL CHARACTER.

The unconsolidated surficial deposits of the quadrangle belong to the Quaternary system and comprise residual clay, glacial drift, and stratified clay, sand, and gravel of Pleistocene age, and alluvium of Recent age. The glacial deposits include drift of the Illinoian and Wisconsin stages, and some scattered fragmentary stratified deposits represent one or more of the interglacial stages. Only deposits of Wisconsin and Recent age are shown on the map, as the older deposits are exposed only beneath the later drift and in areas too small to be mapped.

PLEISTOCENE SERIES.

RESIDUAL CLAY.

Old residual clay, formed by the weathering of the underlying indurated rock, is exposed beneath the glacial deposits at several places in the quadrangle. At one place it is overlain by Illinoian till, so it is at least as old as pre-Illinoian. Its formation probably began in the Mesozoic era and continued until well along in the Pleistocene epoch.

At Hyattville, in the valley of a little stream half a mile southeast of the station, the following section is exposed:

Section at Hyattville.

	Feet.
Till, yellow, fresh and loose (Wisconsin)	7
Till, blue, hard and jointed (Illinoian)	6
Sand, stratified and much weathered, thickness uneven	2
Clay, dark, rusty, hard and jointed, without admixture of foreign material, grading into shale beneath	2

About 1 to 1½ miles south of Africa, between the little runs that enter the Olentangy from the west, the glacial deposits are exposed at several excavations made in grading the road. Here the Illinoian till is lacking, so that the fresh Wisconsin till rests directly upon dark residual clay that grades into weathered shale, which in turn grades into sounder, firmer shale at the base. Several other similar exposures were found.

In the limestone quarries south of the Scioto and half a mile north of the insane asylum at Columbus, residual clay and chert, containing no glacial material, fill crevices between weathered blocks and along bedding planes of the limestone. Similar occurrences are found in the large quarries at Marble Cliff and elsewhere. (See fig. 6.)

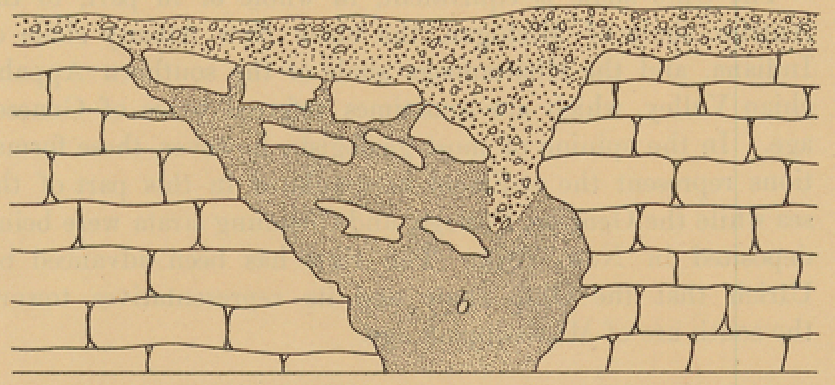

FIGURE 6.—Cavities in limestone filled with preglacial residuum of clay and chert.

About 3½ miles west of Union Station, Columbus. *a*, Glacial drift; *b*, residual chert and clay with no foreign pebbles.

All these bodies of residual material show that the indurated rocks had been deeply weathered and that a fairly thick layer of rock waste had been formed before the Illinoian ice invasion.

PRE-ILLINOIAN ALLUVIAL AND LACUSTRINE DEPOSITS.

At a few places alluvial and lacustrine deposits are exposed beneath Illinoian drift. Along Glenmary Run, 10 to 11 miles north of Columbus, plastic and arenaceous clays, 60 to 70 feet thick and having a known horizontal extent of half a mile north and south and nearly as much east and west, lie beneath characteristic Illinoian till. Some of the clay is blue and contains small, button-like, calcareous concretions and some is yellow and contains ferruginous clay concretions. Both sorts are profusely jointed and in places rather sandy. The exposures seem to indicate that the material is of local distribution and that it occupies part of a pre-Illinoian valley.

At another locality, half a mile up the run from the sandstone quarry northeast of Reynoldsburg, the following section is displayed beneath fresh yellow drift of Wisconsin age:

Section of Illinoian and older deposits northeast of Reynoldsburg.

	Ft.	in.
Drift, jointed, indurated, and containing concretions (Illinoian)	1–8	
Sand, fine, no fossils		3–6
Clay, blue, sticky, containing many decayed leaves and stems		3–4
Sand, fine, containing many fossil shells		6±

No other exposure of this deposit has been found. The fossil shells, which include several species of small gastropods and one or more of pelecypods, were all identified by Calvin and Shimek as modern forms, but as there has been little change in land and fresh-water mollusks in Quaternary time, they do not serve to fix the age of the deposit. Its position beneath the Illinoian till indicates that it was laid down during one of the earlier interglacial stages, possibly the Yarmouth.

Many wells have penetrated gravel and sand and even quicksand beneath the hard blue Illinoian till. Not many of these wells pass through the gravel, but in most of those that do the gravel is said to lie directly on bedrock. Such deposits of gravel and sand are not confined to any one part of the quadrangle, but they seem to be local, as if formed in buried valleys. Similar gravel also occurs beneath outwash drift of Wisconsin age in the bluffs along the Scioto at Columbus.

ILLINOIAN DRIFT.

Throughout much of the quadrangle, as is shown by more than 75 widely scattered exposures and scores of wells, the Wisconsin is underlain by an uneven layer of compact, indurated, jointed, bluish or brownish till, which is at many places weathered and cemented along the joints. The weathering is accompanied by a change of color of the till, and where the till is eroded by streams the cemented material stands out in relief above the less resistant, less weathered, and less cemented portions. Much of this older till contains carbonates, which are in part at least original ingredients. They may, however, include some cementing material that was either introduced or dissolved and reprecipitated, a fact that would account in part for the greater hardness of the old till. In this till calcareous concretions are abundant and pebbles are common but bowlders are rather rare. At many places such fragments are much weathered, especially those that lie near a joint or near the surface of the deposit, at other places they are but little weathered. The limestone pebbles are probably the least weathered, as many of them still bear perfectly preserved glacial striæ, but most of the pebbles of igneous and metamorphic rocks are more or less oxidized, kaolinized, iron stained, and generally disintegrated. The thickness of this old till at some places is more than 100 feet but most of the exposures show less than 20 feet. The material is referred to the Illinoian drift on account of its character and its relation to the Wisconsin drift and is correlated with the more extensive deposits of Illinoian drift in other parts of the State.

INTERGLACIAL BEDS.

Traces of an interglacial soil that is intermediate in age between the Illinoian and the Wisconsin drift have been found at four places in the quadrangle. On the north side of the east branch of Glenmary Run about a quarter of a mile above the junction of the two branches the yellow stratified clay described in a previous paragraph outcrops in the bed of the stream and is overlain by characteristic Illinoian drift. The Illinoian is in turn overlain by Wisconsin drift, from which it is separated by a thin zone of dark weathered soil of interglacial age.

On the north side of Springwater Run a short distance above its junction with Darby Creek, just south of Harrisburg, interglacial beds are exposed as shown in the following section:

Section of Pleistocene deposits near Harrisburg, Ohio.

	Feet.
Till, yellow, loose and unweathered (Wisconsin)	30
Loess, light gray, like that of southern Illinois	1
Sand, fine, weathered, and sandy till (Illinoian?)	3
Gravel, coarse and weathered, having a smooth, sharp contact with overlying bed (Illinoian?)	1
Till, blue, compact and jointed (Illinoian)	5

At the bend of the stream north of the road about 2½ miles west of Matville interglacial deposits are exposed and the following section was measured:

Section of Pleistocene deposits west of Matville.

	Feet.
Drift, fresh, with fresh gravel at base (Wisconsin)	10
Soil-like material, dark and weathered (Sangamon?)	1
Bowlder clay, old and indurated (Illinoian)	3

A section in the east bluff of Darby Creek half a mile north of Orient is as follows:

Section of Pleistocene deposits north of Orient.

	Feet.
Soil, dark, and weathered till grading down into underlying material (Wisconsin)	3–4
Clay, yellow and stony, fresh and loose, with sharp contact with bed beneath (Wisconsin)	12–15
Soil-like material, dark, compact, and much weathered, grading into next below (Sangamon?)	2–4
Till, blue, old, and dense (Illinoian)	50

About 4 miles south of Columbus, west of the Scioto, the little stream that heads near Grove City is cutting into old peat. At least 4 feet of such material is exposed, half below the water and half above, and it is overlain by fresh drift in the bluffs on both sides. The stream has apparently cut into an interglacial peat bog.

Although the old soils and peat are exposed at only a few places those places are widely scattered, and the exposures are important as evidence of at least one interglacial interval in the region.

WISCONSIN DRIFT.

Older Stratified Deposits.

At two places gravel and sand lie beneath Wisconsin drift in situations that establish their connection with the Wisconsin stage. A little more than 1½ miles north of Reynoldsburg, in the east bluff of the run flowing southwestward, is an excellent exposure of sands and clays, more than 20 feet thick. The beds are horizontally stratified and consist of clay and very fine sand, but apparently contain no organic remains. Two layers of sand show very perfect ripple marks that are 5 inches from crest to crest and 1 inch high, and were presumably formed in a fairly large body of standing water.

Near the suspension bridge over Rocky Fork, 1½ miles east of Gahanna, in a valley cut in Illinoian drift, is a deposit of stratified sand and gravel. It is apparently outwash laid down prior to the deposition of Wisconsin drift, 25 feet of which overlies it.

A number of well records reveal the presence of gravel between the Wisconsin and the Illinoian drift at other places, if the identifications of those deposits in the wells are correct.

Till.

Ground moraine.—The material constituting the ground moraine or general till sheet of the Wisconsin stage is ordinarily loose, slightly weathered, yellow to buff or brown bowlder clay, consisting of clay, sand, pulverized rock, and rounded and angular pebbles and bowlders in great variety of size and composition. The ingredients are not uniformly mixed and different sorts predominate in different places, resulting in gravelly, stony, sandy, and clayey phases of the till. Likewise the proportions of the rock types differ greatly according to the sort of local rock most freely gathered by the glacier. In the eastern and southeastern parts of the area sandstone is abundant in the till; in the western part limestone is the most abundant material; and in the central part clay from the shales and chert from the Delaware limestone are abundant. Crystalline rocks brought from a distance probably do not constitute more than 5 to 25 per cent of the stony material anywhere. The thickness of the till differs greatly from place to place, ranging from almost nothing to more than 100 feet. The base on which it rests is probably more uneven than its surface was when it was first laid down.

The surface of the ground moraine is remarkably even throughout a large part of the area, but even where it is most nearly level the material differs somewhat from place to place. Darker areas, rich in humus, the larger of which show obscure stratification, break the general gray or yellowish color of the soil. These areas are especially noticeable in the spring, when the ground has been prepared for planting and before the crops have obscured the surface. They are interpreted as former slight depressions, in which deposits of peat and surface wash were formed.

In the hilly belt in the northeastern part of the quadrangle the surface of the general till sheet is diversified by conical to ovoid, rather steep sided, generally isolated small hills or tumuli of stony till. The material is largely of local origin and the fragments are mostly subangular. One such tumulus contains stratified sand.

Bowlders.—Many bowlders of igneous and metamorphic rocks brought from a distance, as well as bowlders of limestone and sandstone of more or less local origin, are scattered through the Wisconsin drift. They may be found in considerable quantities in streams just below large cuts in drift from which they have been sorted. A few lie on the surface or are but partly covered. The largest are igneous or metamorphic rocks and a few weigh 25 to 40 tons each. Many, like the pebbles, have flattened faces and smoothed, grooved, or striated surfaces. Among the most interesting are bowlders of a breccia-like rock, consisting of large and small fragments of many sorts of rocks embedded in a dense, hard, green matrix. Here and there single bowlders contain fragments of ten or twelve different sorts of rock, some flat faced and angular, others rounded. Some are made up almost wholly of pebbles, with but small masses of matrix, others consist almost entirely of matrix with a few small pebbles. The matrix is fine grained, felsitic or even crystalline, and generally greenish. In some specimens it might be called graywacke, in others it is more nearly a mica schist, and in still others it resembles felsite, but there are no signs of contact metamorphism of the pebbles by the matrix. It is believed that these bowlders are fragments of an ancient till that has been indurated and somewhat metamorphosed; its matrix of clay and pulverized rock have become graywacke or mica schist but the pebbles remain comparatively unaltered. If this belief is well founded the bowlders probably came from the lower Huronian formation of middle and northern Ontario, which Coleman[1] has described as a metamorphosed drift deposit.

Moraines.—Moraine loops that rise a little above the till plain cross the quadrangle as shown on the surficial-geology map. The southernmost one curves across the hilly tract in the southeast corner of the quadrangle near Marcy. It is hummocky and pitted with kettles, now mostly drained. Outside the kettles the drift is stony and contains angular fragments from the bedrock of the hills at the north and rounded or flattened fragments of limestone, granite, and gneiss from more distant places. About 4 miles north of this lies a second moraine, which is more ridgelike and much less kettled. It skirts around the hills from Jefferson toward Lithopolis and attains a thickness in places of 60 to 80 feet or more. For 2 or 3 miles near Lithopolis the moraine is lacking. About 1 mile west of the town it begins again and continues as a hillside terrace, next as a ridge, and finally it flattens to a gently rolling area on the plain, into which it merges completely and disappears. It is thinner west of Lithopolis than east of it.

At several places around Waterloo and southeast of Groveport there are areas of thickened hummocky drift with kettles, some of which still contain ponds or marshes.

A belt of thickened drift that assumes definite morainal form enters the quadrangle from the northeast at a point east of Center Village. Southeast of the village it is even better developed and is characterized by ridges, tumuli, and groups of hummocks. It continues more or less interruptedly southward past New Albany, Ovid, Taylor, and Brice; then is lacking for 4 miles, but it rises in deep masses of drift with fair morainal form northwest of Groveport and is traceable to the ridge and moraine area north of Lockbourne and Shadeville. West of the Scioto and south of the latitude of Columbus the Wisconsin drift is everywhere thick. Many wells penetrated it 30 to 60 feet before reaching the older, harder drift below. Throughout this tract, however, the surface expressions of uneven thickness are rare and unsystematic. Many little swells are found in the southern part of the quadrangle, near Commercial Point and Matville and west of Harrisburg. Another area of swells, some of them hummocks, is found along Scioto Big Run, and another lies west of the cemetery southwest of Columbus and continues westward past Camp Chase Avenue, Alton, and southward nearly to Galloway and on westward across Darby Creek.

[1] Coleman, A. P., The lower Huronian ice age: Jour. Geology, vol. 16, No. 2, pp. 149–158, 1908.

Thickened drift with a morainic surface occurs near the northeast corner of the quadrangle. By means of scattered hummocks, short ridges, and a few kettles the belt of moraine can be traced from the northeast corner of the quadrangle, near Condit, westward nearly across Trenton Township, thence southwestward across Walnut Creek to a point 3 miles south of Galena, thence southward past Westerville to Blendon. From Minerva Park southward to Mifflinville the distinctive morainal form is not found, but the Wisconsin drift is thick and at many places the combined thickness of the Illinoian and Wisconsin exceeds 100 feet. Rather distinctive morainal form again appears south of Linden Heights.

The Powell moraine lies in a broad belt extending from Sunbury southwestward past Galena and Africa, midway between Orange and Flint, past Powell, Jerome, and New California, and westward out of the quadrangle. In some places the thickness of the drift in this moraine, as shown by wells, is 150 feet, but probably half the thickness is made up of Illinoian deposits. At several places, where hummocks and kettles are lacking, the thick accumulation of drift constitutes the best evidence of the presence of the moraine, but the belt also includes many areas of typical morainal form. Most of the drift of the Powell moraine in the western half of the quadrangle, especially as reported by well drillers at New California and Powell and as seen in exposures, is compact and suggests a submarginal origin. Immediately north of the moraine the drift is thick, but it becomes perceptibly thinner within 2 or 3 miles.

Later Stratified Drift.

Outwash.—The outwash gravel and sand of Wisconsin age are generally fresh, but little stained, and rarely cemented. They range in thickness from a few inches to 100 feet. Such deposits are most common along present drainage lines but are by no means confined to such lines. A level sandy plain lies south of the moraine at Shadeville and east of Lockbourne, and a level, sandy area comprising 4 or 5 square miles lies south of the Powell moraine and east of Flint. A patch of gravelly outwash lies between Baker Hill and South Columbus. It is much larger than it appears at the surface, because it is covered by later drift, 20 to 50 feet deep, for at least 3 miles south and southeast from its outcrop. Deposits of Wisconsin outwash are very meager for a region containing so large a moraine as the Powell.

Kames and eskers.—The kames forming Baker Hill and the group at Spangler Hill are the most typically developed and by far the thickest in the area. Those at Spangler Hill are shown in Plate I. At Baker Hill, where the deposit is more than 50 feet thick, the stratification is greatly confused, folded into short kinks, and broken; at Spangler Hill, where the deposit is more than 100 feet thick, oblique but not confused stratification is found.

The surficial-geology map shows five eskers and several detached fragments of gravel ridges. They consist of gravel and sand, as thoroughly washed as can be found in the quadrangle, and all have been opened as sand and gravel pits. The stratification is far from regular; in many places it is cross-bedded, and here and there the beds are tumbled and confused at the margins. Flat pieces in these deposits lie in positions which indicate that the stream which laid them down flowed southward. The pebbles in the deposits of these three types—outwash plains, kames, and eskers—are of as many sorts of rock as are found in the moraines, but they are rounded and smoothed and few of them have striated faces. The gravel in them descends lower than the till plain, in many places several feet lower. In the esker 2 miles northwest of Brice the sand and gravel are 70 feet thick, although the ridge rises but 30 feet above the till plain. Many of the kames and eskers are capped by till and some are covered with bowlders in addition. Of the last type the esker just mentioned forms the best example. Of the type with till and no conspicuous bowlders the Irish Hills and Baker Hill are the best illustrations, and on Baker Hill the very top seems to be free from drift, although it lies far up on the sides.

Other sand hills and ridges of Wisconsin age are the kames at Pinhook on Walnut Creek and the fragments of esker ridges aligned southward therefrom for 4 or 5 miles. The sand is not well assorted or stratified but has been used more or less for roads and cement work. The ridges fail and the sand and gravel plain begins about 1 mile north of Gahanna. This sheet of stratified sand and gravel, broken by erosion, continues southward from Gahanna for 1½ miles with a thickness of 10 to 30 feet. It does not rise above the general level of the drift on either side but is essentially as high.

In the south-central part of the quadrangle, just east of the Scioto Valley, there are a number of inconspicuous esker-like sand ridges. The deposits seem to be rather deep and consist of fine, clean sand. Several other gravel and sand bodies occur in the drift as fragments of outwash deposits or sections of eskers or kames.

Lacustrine deposits.—Several deposits of lacustrine clay and sand overlie the Wisconsin drift. As their accumulation began while the ice was still near they are classed as Pleistocene, although their deposition may not have been completed during that epoch.

A lacustrine deposit covering about a square mile lies 1 to 2 miles east of Lithopolis. It consists of light-gray clays and fine sands across its central part and a sandy zone around its margin. Its thickness probably nowhere exceeds 6 or 8 feet and actual shore-line phenomena are very weak. South of Galloway there are three or four lake beds covering 100 to 150 acres. The surface layers are a rich black soil. Stratification is not well defined and the total thickness of the beds is probably not more than a few feet. These areas are becoming more and more obscured by cultivation. North of Canal Winchester there are two more patches of lake deposits. The larger is about 3 miles from town and consists of sandy clays and of peaty areas that are still more or less swampy. In the eastern part of the Spangler Hill kame group, 4 to 5 miles south of South Columbus, there is a kettle lake bed, now thoroughly drained and floored with fine black soil. The former shore lines and a small sand bar can be traced by the sand deposits around the peaty central portion. The surface of the deposit is remarkably level and smooth, as shown in Plate II, and the stratification is plain. The accumulation is but a few feet thick, and probably came largely from moraines on the east, shown in the distance in the picture. In the Powell moraine south of New California there is a small lake bed. The deposits consist of clay, sandy clay, and, toward the margin, sand. It is a kettle in the moraine occupied by a lake through which Sugar Run flowed. The deposits were brought by the stream or by surface wash from the surrounding moraine. Deposition is now complete, the kettle is full above the present outlet and the stream drains the bed perfectly. In many places over the drift there are small areas of lake, pond, or swamp deposits consisting of clay and peaty clay. These are too small to be shown on the map but in the aggregate constitute many acres.

Much fine material has been washed from the higher parts of the general till surface and redeposited in the depressions, and such rearrangement of material contributed in no small degree to the formation of a generally even surface. The deposits, which are not stratified, range in thickness from a few inches to several feet. In many of them it is impossible to distinguish between Pleistocene and Recent material, inasmuch as the formation of peat and muck is still going on.

STRUCTURE.

The Paleozoic strata of the Columbus quadrangle must originally have been nearly level, but although the quadrangle lies in a region that has been comparatively free from deformation they have from time to time been subjected to gentle uplift and warping and now dip eastward at the rate of 20 to 30 feet to the mile. (See fig. 7.) The quadrangle is situated on the eastern flank of the Cincinnati anticline and the easterly dip of the strata may be due largely to that fact. Several low cross folds extend from west to east across Scioto and Olentangy rivers, in the northern part of the quadrangle, and apparently die out eastward. Most of them are gentle, but two are of such magnitude as to bring the contact between the Delaware and Columbus limestones 50 feet above the level of Olentangy River, whereas at points both upstream and downstream the contact passes below water level.

During the great deformation that affected much of eastern North America near the close of the Paleozoic era the strata were subjected to warping and two well-defined sets of joints were formed. These two sets are approximately at right angles to each other and trend northeastward and northwestward respectively. Jointing is especially well developed in the Ohio shale along Rocky Fork and in the Sunbury shale and the Cuyahoga formation south of Lithopolis. In the limestone, chiefly along Scioto River, ground water has widened the joints by solution so much that many of the small streams flow partly or wholly in subterranean channels, some of which discharge their water at the foot of the bluffs along the river.

Besides the joints a few faults of slight displacement were formed. Several faults were noted along Rocky Fork, where they are most conspicuous in the Bedford shale. Those seen in that part of the narrow valley near the contact between the Bedford shale and the Berea sandstone are probably due to slumping, during its deposition, at the margins of the thick deposit of mud that now forms the shale. This produced local distortion of the beds, which in many places resembles folding. Upon these distorted strata the Berea sandstone lies in comparatively undisturbed condition.

The widespread submergence was brought to a rather sudden close by renewed uplift and the introduction of conditions favorable to the deposition of the clayey material that formed the Utica shale, which is generally black. Much of the surrounding territory had then emerged from the sea and the abundant sediments that formed the shale resulted from the weathering of areas of limestone.

The deposition of the mud which formed the Eden shale was probably continuous with that which formed the Maysville and Richmond formations, the time of deposition being one of preponderant transgression of the sea. In the southwestern part of the State, where these formations outcrop, Foerste has worked out the interesting faunal oscillations resulting from alternating incursions of the sea from the north and the south. Richmond deposition was terminated by the uplift of the Cincinnati anticline, when a large part of southwestern Ohio became land and perhaps has never since been entirely submerged. This upward movement affected the Columbus quadrangle and may have converted into land a much greater portion of the State, and even of the continent, than now appears probable.

SILURIAN PERIOD.

After the uplift the first sediment deposited during renewed submergence was a red clay which probably represents the weathered or oxidized detritus eroded from the newly uplifted shale areas. As the sea deepened and widened the "Clinton" beds were deposited, in some places as calcareous mud but in many others as clay or perhaps even as sand. With the elevation of the old eastern land mass known as Appalachia and the rejuvenation of its streams, which probably occurred about this time, the "Clinton" phase of deposition passed gradually into that of the Osgood shale and finally into the period of dolomite deposition represented by the Springfield and Cedarville limestones. During the later part of Niagaran time, represented by the last-named formations, calcareous mud, now forming limestone and dolomite, was in process of deposition over a greater area than at any time since the Trenton epoch, and the sea was filled with numerous forms of life. A change of climate, with perhaps a shallowing of the epicontinental sea, brought about the deposition of the impure calcareous and gypsiferous beds of the Monroe formation and finally the recurrence of land conditions brought the close of the Silurian period. With the exception of a few small outcrops of the Monroe formation, the unconformity representing this interval of land conditions forms the first record in the Columbus quadrangle that can be directly observed.

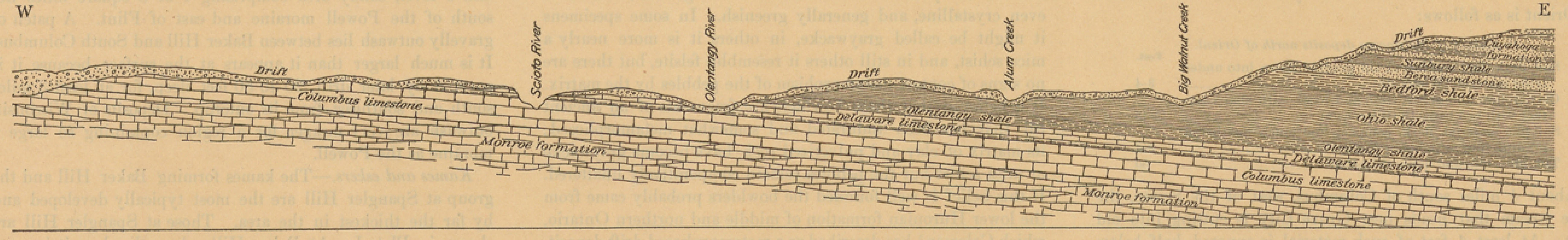

FIGURE 7.—Geologic section from west to east across the Columbus quadrangle, in the vicinity of Columbus.
Shows the uniform eastward dip of the rocks beneath the mantle of drift, successively higher formations appearing at or near the surface toward the east.
Horizontal scale: Same as map. In order to avoid undue exaggeration of the dip of the beds the thicknesses are not drawn to scale.

RECENT SERIES.

ALLUVIUM.

The valley of the Scioto from Grandview southward is floored with alluvium to a width of a mile or more, and similar deposits, which at some places are as much as half a mile wide, floor the valleys of the other large streams. In many of the minor valleys there are little strips and patches too small to be shown on the map. As the streams are engaged mainly in degrading rather than aggrading their beds the alluvium is nowhere thick, generally not more than 10 or 12 feet. In some of the deforested lateral valleys it has in places accumulated to a depth of 20 feet, and in general the alluvium in such valleys is much thicker than that in those in which the timber yet remains. Most of the alluvium forms flat flood plains, but thicker portions here and there form sand bars that rise 10 feet or more above the general flood-plain level. Some of the alluvium lies on rock terraces.

The alluvium is generally sand, gravel, or fine sand grading into clay. It was evidently derived from the material that borders the streams. Where that is drift the alluvium is mainly clay, but includes some sand composed of fragments of quartz and other minerals, and many bowlders and stones, also derived from the drift. The material is roughly stratified, the bowlders and coarser material below and the finer above, and the clay and silt at the top. Where the valley walls are limestone the alluvium is generally meager and consists chiefly of drift washed in from the sides or from upstream. It contains some pebbles of limestone, however, and in places, as on some of the rock terraces along the Scioto, it includes some residual clay and chert derived from the limestone. Where the valley is cut in shale, as along Olentangy River and Alum Creek, the alluvium contains many fragments of shale as well as material derived from the drift. Along Blacklick and Walnut creeks and many of their tributaries fragments of sandstone and shale are abundant in the alluvium. Like the material derived from the drift, they are roughly sorted, and the flatter pieces assume a stable position, pitching upstream.

On the flood plains in many places other poorly stratified deposits form alluvial fans. The material composing them is of the sorts found in the flood plains but is generally coarser.

GEOLOGIC HISTORY.

PALEOZOIC ERA.

EARLY PALEOZOIC TIME.

The geologic history of the Columbus quadrangle in early Paleozoic time must be inferred from what is known of the general history of the region in which the quadrangle is situated. During a large part of the Paleozoic era, at least after Middle Cambrian time, the quadrangle was submerged beneath the waters of an interior sea and received deposits similar to those of early Paleozoic age found in neighboring regions.

The earliest event recorded in the rocks known to underlie the quadrangle was the deposition, early in the Ordovician period, of a bed of almost pure quartz sand, now forming a sandstone that is correlated with the St. Peter sandstone of the Mississippi Valley region. Just previous to the deposition of this sand the Columbus region had probably been land, and, on the return of the sea, sand formed of detritus of the old crystalline rocks on the north or of sandstones, such as those of the Upper Cambrian, was spread over the submerged area.

This event was followed by a considerable deepening and rapid spreading of the sea, involving the whole area of the State and reaching its climax in Trenton time. The several stages in this transgression of the land by the sea, during which the calcareous mud that now forms the earlier Ordovician limestones was deposited, can not be determined from the well records, but the shore line probably oscillated back and forth, as in adjoining regions.

DEVONIAN PERIOD.

Columbus sedimentation.—During the early part of the Devonian period the quadrangle, and probably the whole of Ohio, was a land area. The Columbus region continued to be land until well into Middle Devonian time, when the sea spread rather rapidly westward over the State, depositing a conglomerate on the eroded surface of the Monroe formation. The waterworn pebbles of this conglomerate are derived from the banded drab dolomite of the underlying formation, which must therefore have been well consolidated before the first Devonian sediments were deposited. Associated with the dolomitic pebbles is a small amount of quartz sand, the origin of which is not known. It is the only possible suggestion of the Oriskany sandstone known in Ohio. The lower part of the Columbus limestone is sparingly fossiliferous and contains a considerable quantity of finely divided carbonaceous matter in the form of films and dark wavy bands. These beds are also dolomitic and probably this portion of the formation was, in large part, derived from the older Silurian dolomites as the sea gradually overspread them. This phase of the formation was followed by a clearing of the sea and the deposition of an abundantly fossiliferous and very pure calcareous mud. The Columbus limestone contains the typical Onondaga fauna, among which are mingled faunal elements derived from Europe and from South America, apparently indicating that there was probably a transgression of the Devonian sea from both the north and the south, mingling the denizens of these foreign seas with those indigenous to North America.

Delaware and Olentangy sedimentation.—The Columbus limestone terminates rather abruptly and is directly followed by the brown shale of Marcellus age, which forms the basal layers of the Delaware limestone as recognized in Ohio. The Delaware contains a considerable amount of detritus that was probably derived from Appalachia, which seems to have received another rejuvenating uplift about this time, as is indicated by the fact that the beds of Marcellus and Hamilton age, scarcely 70 feet thick at Columbus, thicken rapidly eastward, reaching a maximum of more than 1,500 feet in parts of Pennsylvania that are near the source of supply. However, after the first influx of clastic sediments, limestone-forming conditions were restored over much of Ohio and adjoining regions and with the change came a return of such Onondaga forms of life as had been able to withstand the Marcellus conditions, and the sea once more swarmed with familiar organisms. Such was the early Hamilton history in Ohio. A little later the sea withdrew only to readvance and bring with it the usual Hamilton deposits of the east, here represented by the Olentangy shale. The fauna of this soft shale is not abundant except in the northern part of the State, where the upper beds are generally filled with specimens of the most characteristic fossils of Hamilton time.

Ohio sedimentation.—After the deposition of the Olentangy shale there was a break in sedimentation, probably of short duration, which was followed by the deposition of a great thickness of bituminous black mud and a subordinate amount of gray mud, which were probably derived chiefly from the low-lying lands of the Cincinnati anticline and similar land areas farther north. These regions were somewhat rejuvenated at the beginning of the Upper Devonian epoch at the same time that the old crystalline area of the east was affected by reuplift resulting in the thick and generally coarse deposits characteristic of the Upper Devonian of New York and Pennsylvania. This uplift produced a quickening of the streams, and the old soils derived from the deeply weathered limestones, mingled with the carbon accumulated from the abundant vegetation, were carried out into the sea and there deposited as the black sediments now forming the Ohio shale.

DEVONIAN OR CARBONIFEROUS PERIOD.

Bedford sedimentation.— The break at the close of the deposition of the Ohio shale is not very marked. In fact some of the fossil species found in the top layers of the black shale appear to be the same as those in the Bedford shale. With the beginning of Bedford time there was a change in the character of the sediment and the introduction of an abundant fauna, but the fossiliferous phase was of rather short duration, as few forms are found more than 2 or 3 feet above the base of the formation. The sea in the region of Ohio appears to have had a somewhat varied history but apparently it persisted nearly to the close of Mississippian time, perhaps sometimes even losing its connection with the open sea, and eventually disappearing chiefly because the basin was filled with sediment. Toward the close of Bedford time thin arenaceous beds began to be deposited in the argillaceous mud. They are well ripple marked and are associated with evidences of old deltas, which thus speak of the offshore conditions that prevailed in the region during that time.

CARBONIFEROUS PERIOD.

MISSISSIPPIAN EPOCH.

Berea sedimentation.—At the beginning of Berea time the deposition of sandy sediments began to prevail in this part of the sea. The sandstone also is ripple marked and contains many lenticular and cross-bedded layers. In parts of the Columbus quadrangle, especially the southeastern part, the Berea is very thin and lies with marked unconformity on the Bedford shale. (See Pl. V.) This unconformity is somewhat general and is especially pronounced in northern Ohio. North of the quadrangle the Berea sandstone thickens materially, and there it is probably in part an offshore formation and in part a land formation. The source of the sand was undoubtedly the old crystalline area on the north. The Berea sandstone contains few fossils other than bits of wood and the scant remains of fishes found in the northern part of the State. In Pennsylvania, however, the "Corry" sandstone, which is the eastward equivalent of a part of the Berea, is very fossiliferous.

Sunbury sedimentation.— Eventually conditions favorable to the deposition of Carbonaceous mud were again restored and with them came an abundant fauna. The number of species is small but some of the individuals were exceedingly numerous. Small brachiopods of the Lingula and Orbiculoidea types are mingled with fish teeth and fragments of plants. The Sunbury is, in fact, a highly bituminous shale, which resembles in some respects the Ohio shale and like that was probably derived largely from the land areas of the Cincinnati anticline.

Cuyahoga and Black Hand sedimentation.—As the sea expanded the sediment was derived less from the old limestone areas and more from the higher regions on the east, so that a considerable amount of sand was interbedded with the argillaceous mud. The material deposited gradually changed to a purer sand and then to coarse sand and gravel.

Later Mississippian time.— About Columbus no record remains of the events that immediately followed the deposition of the Black Hand formation. Only a few miles to the east, however, that formation is overlain by the Logan formation, and that in turn is overlain unconformably by the Maxville limestone, and probably both once extended westward over the Columbus quadrangle. Presumably, therefore, deposition continued in the quadrangle through Logan time, while more sand was being laid down, but was then terminated by emergence of the area. After an interval of erosion the region was again submerged and a calcareous mud, now the Maxville limestone, was deposited.

PENNSYLVANIAN AND PERMIAN EPOCHS.

Pottsville time. — At the close of Mississippian time a widespread emergence of the region took place and the interior Paleozoic sea was reduced to a mere remnant of its former self. During the ensuing interval of erosion the Maxville limestone was largely removed and in places even the upper part of the Logan formation was cut away, and the region was reduced to a peneplain, over the surface of which the coarse gravel of the later Pottsville transgression was spread. No such deposit now covers any part of the Columbus quadrangle, but it is found about Newark, only 30 miles to the east, and probably once extended westward beyond Columbus.

Deposition of coal-bearing beds.—During the rest of Pennsylvanian time and the early part of Permian time southeastern Ohio was low and flat and lay nearly at sea level. At times it was slightly submerged and received thin deposits of sand, clay, or limy ooze. At other times it was slightly elevated, but the greater part of the surface was covered with swamps and a dense plant growth. Streams ran here and there across the surface, cutting shallow channels in the recently deposited and still unconsolidated beds. Vegetal débris accumulated in the swamps or was washed away and redeposited in deltas and estuaries, forming thick beds which in the course of time have become dried out, compacted, and altered into coal.

In the Pittsburgh syncline many alternate beds of sand, clay, and vegetal débris and a few thin beds of calcareous mud, some of them highly ferruginous, were deposited before the close of Carboniferous time. The sea bottom seems gradually to have subsided as the sediment was accumulated, so that the sea was probably never deep, although the total thickness of the coal measures in the middle of the basin is nearly if not fully 3,000 feet. Southeastern Ohio was near or at the margin of the area of deposition and the thickness of the coal beds there is considerably less.

The denudation of the surface since Carboniferous time has been sufficient to remove the marginal beds, so that it is uncertain whether the Columbus area was ever submerged after Mississippian time. On the other hand there is no doubt that during much of Pennsylvanian time it was a land area that contributed its share of detritus to the formation of the later Carboniferous strata in the basin.

Deformation of the strata.—The great deformation that affected most of eastern North America at the close of Carboniferous time seems to have only slightly disturbed the rocks of the Columbus quadrangle, but such disturbance as they have undergone was produced largely at that time. The strata were tilted eastward—away from the Cincinnati anticline and toward the Pittsburgh syncline—were gently warped into the low cross folds described under the heading "Structure" (p. 10), and were jointed. The area was uplifted, certainly several hundred feet above sea level, possibly a few thousand feet, and the surface was probably thrown into low wrinkles that conformed to the warping of the rocks.

Throughout the period of deposition of the Carboniferous strata the general slope of the surface in the Columbus area must have been southeasterly, toward the middle of the Appalachian coal basin, and as the folding of the rocks progressed and the basin became a syncline of deformation as well as of deposition the southeasterly slope must at first have been augmented. The general result of the uplift, however, was to give the surface of the western part of the province a gentle slope to the northwest or west and a like direction to the main streams.

MESOZOIC ERA.

In the region about Columbus there is apparently no record of the early part of the Mesozoic era, as all the topographic features formed then seem to have been destroyed by later erosion. The general course of events, however, can be inferred from what has been learned of the history of other parts of the Appalachian province at that time. At the beginning of the era the surface of the quadrangle, like that of the rest of Ohio, must have stood at least several hundred feet above sea level, and sloped gently to the west or northwest. The main streams had their sources far to the southeast, near the axis of the uplift, and must have flowed across the region in a general westerly or northwesterly direction. So far as is known the region was land throughout Mesozoic time. The surface was greatly lowered by prolonged denudation and passed through at least two cycles of erosion, separated by uplift. In each cycle the region was reduced to a nearly featureless plain that lay but little above base-level.

No trace of the older of the two plains, the Cumberland peneplain, now remains in the quadrangle. Early in Cretaceous time, however, the area was probably part of a plateau of moderate altitude, the uplifted Cumberland plain, whose surface also had a general northwesterly tilt and across which the main streams still flowed northwestward. During the Cretaceous period the region was again reduced to a peneplain, which is approximately represented by the remnants of the Allegheny Plateau in central Ohio. Near the end of the period, as far as can be determined from the available evidence, the region was again uplifted a few hundred feet and the rejuvenated streams began to dissect the new plateau.

CENOZOIC ERA.

TERTIARY PERIOD.

Dissection of surface.—The record of Tertiary time in the area is also wholly one of erosion. The uplift that converted the Cretaceous peneplain into a plateau seems to have been greater toward the northeast, so that the new plateau was probably tilted gently to the west or southwest. Apparently, however, the uplift was so gradual that the main streams cut down their beds as fast as the land rose and thus continued in their northwesterly courses. The plateau has been so much dissected that in the Columbus quadrangle it is represented only by the hilly belt along the east side of the area and in the southeast corner. During this cycle of erosion a great part of the surface of northern Ohio was again reduced nearly to base level, forming the Erie Plain, and the surface of the Columbus quadrangle was also considerably reduced.

Except for a few buried gorgelike valleys of possibly early Pleistocene age and for such grinding down of the surface as may have been done by the ice, the bedrock surface of the quadrangle received practically its present form during Tertiary time. Though by no means closely approaching reduction to a new base level, the dissection of the surface proceeded well past maturity and the resultant topography was of the old-age type, characterized by a broadly rolling surface, with open valleys, low divides, and gentle slopes. Weathering penetrated to a considerable depth and the surface was mantled by a thick blanket of residual soil and rock waste. Joint fissures, especially those in limestone, were widened by weathering and solution and filled with residual clay and pieces of chert. In the limestone formations sink holes were developed and much underground drainage was established. The local base level of erosion at that time was evidently lower than now, as both the underground channels and the bottoms of the valleys in the bedrock surface are below the present drainage level and quite as many underground channels seem to lead away from the present main surface drainage lines as toward them.

Preglacial topography.—The form of the bedrock surface beneath the drift has been partly worked out in the quadrangle from data obtained in wells and stream cuts. It is highest in the northeast and southeast corners, moderately high across the northern part, and lowest in the central-southern part. It thus corresponds in general form to the present surface, but has somewhat greater relief. In the northern and western parts the old surface was broadly rolling and unbroken by large hills or valleys. In the southeastern part it was crossed by a wide valley that entered from the east near Pickerington and left near the middle of the south side and had much the same form and position as the present lowland plain. A small tributary valley led southwestward from a point near Powell and joined the main valley south of Columbus.

The large valley was part of a valley described by Tight,[1] and was that of a Tertiary stream—"Newark River"—which drained east-central Ohio and flowed in a general westerly direction across this part of the State. A little south of the Columbus area it was joined by a stream that flowed northward through the valley of the present lower Scioto River and carried the drainage of much of southern Ohio and West Virginia. The combined stream probably flowed northwestward toward Indiana, but its farther course is not known.

QUATERNARY PERIOD.

PLEISTOCENE EPOCH.

EARLY PLEISTOCENE TIME.

Nothing is certainly known concerning Pleistocene events in the quadrangle before the invasion by the Illinoian ice. There is, however, no evidence of any earlier glaciation, and so far as can be inferred from present knowledge the conditions

[1] Tight, W. G., Drainage modifications in southeastern Ohio and adjacent parts of West Virginia and Kentucky: U. S. Geol. Survey Prof. Paper 13, 1903.

remained practically the same as they had been in late Tertiary time. The existence of the gorgelike buried valleys containing Illinoian drift shows, however, that erosion was accelerated, at least in places, before the Illinoian ice reached the area, as, manifestly, slopes as steep as those of their walls could hardly have been formed in the same erosion cycle with the old-age topography characteristic of the quadrangle at the close of the Tertiary. That the gorges were carved by rejuvenated erosion caused by uplift at the beginning of or early in Pleistocene time is possible, but they seem to bear no relation to the previous topography and cut across from one old valley to another in a manner hardly consonant with such a mode of formation. Another possible but wholly conjectural explanation of these gorges is that they are due to a disturbance of the normal drainage by a pre-Illinoian ice sheet that came near but did not reach the quadrangle. However, no facts have been discovered in the quadrangle or its immediate neighborhood that support either of these hypotheses, and a third one, stated under the next heading, seems on the whole to be more probable.

ILLINOIAN GLACIATION.

The Illinoian ice sheet presumably entered from the north, as did the later Wisconsin ice, in a great rounded scallop known as the Scioto lobe, which occupied the space between the highlands near Bellefontaine on the west and those extending from Mansfield southward past Newark and Carroll to Chillicothe on the east. The ice was probably so thick at times as to cover many of the bordering hills and it certainly covered all the area between. It removed and carried away most of the thick mantle of rock waste and residual clay and smoothed and striated the firm bedrock. It also left a nearly continuous cover of drift in the area when it had again melted away.

The most reasonable explanation of the buried gorgelike valleys containing Illinoian drift seems to be that they were carved during the advance of the ice sheet by streams that were disturbed or forced out of their natural channels by the ice. A lake was formed in front of the advancing ice in a youthful valley at Glenmary and beds of sand and clay were spread over its bottom. Outwash deposited by streams flowing from the ice as it came on was later overridden by the glacier and covered with a sheet of till.

INTERGLACIAL TIME.

Only a meager record is preserved of the events of the interval between the disappearance of the Illinoian ice and the invasion by the Wisconsin ice. There is no evidence of other glaciation during the interval. The surface of the Illinoian till was leached and weathered and much fine loose material was blown about by the wind and redeposited to form accumulations of loess. The climate was as genial if not more so than at present, and the area was reoccupied by vegetation and by animal life, a soil was formed over the surface of the Illinoian till, and vegetal remains were accumulated in places.

The most striking records of interglacial time preserved in the quadrangle are a score or so of small valleys carved in Illinoian till or through that material into bedrock and later partly or wholly filled by Wisconsin drift, but now revealed here and there by Recent erosion. They are the work of interglacial streams, which naturally were directed by the form of the surface of the Illinoian till, and they bear no systematic relation either to the pre-Illinoian topography or to that of the present time. The present streams cross them nearly at right angles in many places. They seem to have attained a much greater degree of maturity than have the Recent valleys, an indication that interglacial time in the area was much longer than that since the disappearance of the Wisconsin ice from the area.

WISCONSIN GLACIATION.

Invasion by the ice.—Early in Wisconsin time the ice again invaded the quadrangle, approaching from the north as before in a broad lobe called the Scioto lobe. (See fig. 8.) The Illinoian drift was overridden, pressed down and packed into its present density, and was probably jointed in places. At a few places partly bedded material was even distorted, apparently by shoving. The ice sheet advanced southward until it nearly reached the Ohio near Cincinnati and deeply covered the Columbus quadrangle.

After the ice sheet had reached its maximum extent the melting back of its margin soon began to be more rapid than the advance of the ice and the ice front began to retreat. At times, however, the rate of advance was equal to or exceeded that of melting back, and the ice margin remained stationary for a time or advanced again for a short distance and then receded, usually building a recessional moraine as it did so. A number of such moraines were formed in the quadrangle during halts in the retreat of the ice front or brief revivals of its advance.

Earlier Wisconsin time.—During the first halt within the quadrangle the moraine that lies around Marcy and extends northeastward and thence eastward to the boundary of the quadrangle was formed. This moraine is the innermost or latest of the moraines grouped by Leverett [1] under the head of "Western member of the eastern limb" of the Scioto lobe. The hills about Lithopolis presented so much obstruction to the glacial movement that the ice front was noticeably held

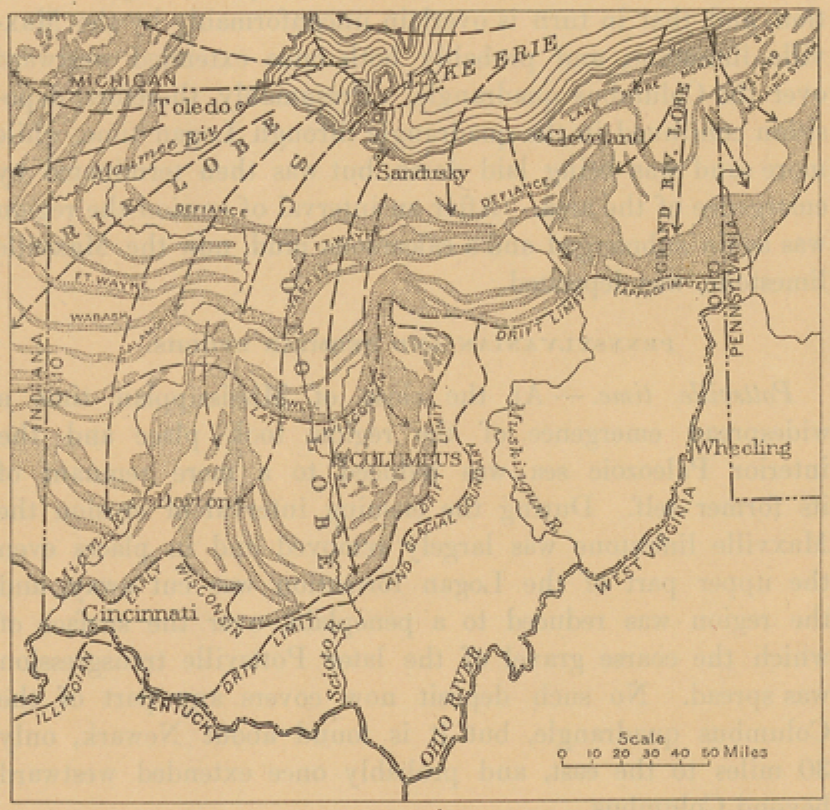

FIGURE 8.—Map of Ohio showing glacial moraines, direction of ice movement, and limits of the drift left by the ice at its several stages.

back there, and across the northern slope of the hills the margin of the ice lay 250 to 300 feet higher than on the plain at the west. During the retreat of the ice after it had built the moraine its melting contributed to the till sheet on the hills between the moraine and Lithopolis.

After the ice had melted entirely off the hills and its margin had withdrawn to the lowland on the north, leaving a sheet of till over the slopes, it seems to have readvanced a little, shoving the drift against the hillsides both east and west of Lithopolis. In the area east of that town two crests, nearly parallel and less than a quarter of a mile apart, record two forward pushes.

The ice front dammed the mouth of a broad valley extending northward from the Lithopolis hills and formed a small short-lived marginal lake in its upper part. The lake received no drainage other than small rills and surface wash, hence no deltas were built in it and shore-line phenomena were but feebly developed about it. The halt of the ice front at this place was probably brief. Most of the moraine was pushed up from the plain rather than freed from the ice by melting.

After it had formed this moraine the ice melted more rapidly. It withdrew from the mouth of the valley and the lakelet was drained. Streams flowing in or beneath the melting ice built the esker ridges southwest of Canal Winchester known as the Irish Hills, in which the positions of more or less flattened pebbles indicate that the current flowed southward, or toward the bifurcated end. Other esker-like ridges between Brice and Pickerington, a group of kames west of Pickerington, and the sand hills and ridges west of Duvall that constitute the north end of the Circleville esker date from this time of retreat.

At this time the Scioto seems to have been a divided stream near the south edge of the quadrangle and to have remained divided for some time, a channel west of the present river carrying some of the Scioto drainage during this substage. Darby Creek also was divided long enough to form the well-developed abandoned valley west of the present stream.

Another minor halt and readvance of the ice front is marked by a series of moraines along a line extending westward 2 miles from the east margin of the quadrangle opposite Center Village, thence southward and southwestward past New Albany, Ovid, Taylors, and Brice, thence northwest of Groveport, north of Lockbourne, and into Shadeville. From Shadeville the position of the ice front is difficult to trace. The moraine and kames that extend 2 miles northward from Shadeville may have been built in a notch or reentrant of the ice front. The abandoned channel east of the kames was the site of a stream at this time but not long enough to become a well-marked watercourse. A stream flowing from the ice developed a channel a mile west of Havens Corners, and a little later another stream 25 to 30 feet lower and half a mile to the west, formed a second channel, which, however, was not used as long as the other.

The size and continuity of the moraine and the difference in the distance between the moraines in the southern and the eastern parts of the quadrangle show that the halt was short, and that it was much shorter in the southern than in the eastern part. The crookedness of the line of deposits indicates a ragged ice front, and the unequal development of the moraine even at closely adjacent points may be due to the irregular distribution of débris in the glacier, which would result in differential melting and an irregular ice front.

While the glacier was melting back from the Shadeville-New Albany stand to the next one northward, the phenomena were similar to those of former intermorainal times. Subglacial deposits and other material were freed gradually, and were scattered over the surface to constitute the intermorainal till plain. Subglacial drainage built an esker a little more than 2 miles west of Reynoldsburg. Later, but during the same recession, the kame-esker-sand plain group from Pinhook to Gahanna was built. About 2 miles west of New Albany an abandoned channel 20 feet deep leaves Rocky Fork valley on the west side and runs parallel to the valley for $1\frac{1}{2}$ miles southward, where it again joins the valley. It was made either by glacial drainage and a divided stream during the retreat of the ice or possibly afterward by a divided Rocky Fork.

Baker Hill, the large kame south of Columbus, was formed during this retreat of the ice front. It was built in such a position with reference to the ice that the final melting left its slopes covered with till nearly up to but not upon the summit. The Spangler Hill group of kames was also made about this time, by drainage from the ice, which piled sand and gravel in heaps, either into notches in the margin of the ice or over the western edge of the lobe. The unequal deposition of drift left a large kettle in the eastern part of the group in which a pond lay for a long time, giving rise to the level plain (see Pl. II) and a rich peaty soil.

The feeble moraine of this substage and of those preceding and following is thoroughly in accord with the scanty supply of outwash which can be correlated with the moraines. Some gravel was carried down the streams from the edge of the ice, but more must have been laid under the ice, as considerable areas along the east side of the Scioto are underlain with gravel and capped with till.

As the ice front withdrew across the intermorainic areas the till plain was completed and left bare. Everywhere a capping of loose light material over the more compact till shows that at least a veneer of drift was left on the final melting of the glacier, but that most of the till sheet was deposited as the ice advanced and was compressed by the weight of the ice. Scattered hummocks and swells and single tumuli of typical drift testify to unequal deposition, but there is little evidence that any such forms were made by water.

Two streams carved channels along the eastern edge of the ice, beginning about 2 miles north of Parks Mills and extending southward, one about half a mile and the other almost to the Mills. The shorter, eastern channel was cut first and in shale and the other in gravel and drift. About $2\frac{1}{2}$ miles northeast of Westerville water flowed outward from the ice across the moraine and carved a well-defined channel.

Other drainage lines established while the ice was melting or stagnant, after the moraine near Shadeville and New Albany was built, and while the streams were beginning their valleys, are shown on the surficial-geology map. A probably subglacial stream built the short esker and sand plain in the northeastern part of Columbus.

Powell substage.—The rather bold southward-facing front and considerable height of the Powell moraine, together with its uniformity in altitude, its lack of kettles, and the total absence of any ice-front phenomena on its inner border, indicate that the moraine is largely submarginal—that is, that the edge of the ice passed over or lay upon the moraine during its accumulation. The western half of the moraine in the quadrangle sustains this interpretation very well, but the eastern part was probably less overridden. As the moraine is at few places less than 1 mile and at many places is 2 miles wide, it seems probable that the ice front alternately advanced and retreated for short distances while the moraine was being formed. The compactness of the drift about Powell and New California further corroborates the interpretation of the Powell moraine as a submarginal moraine smoothed and packed down by overriding ice.

The Powell moraine represents a much longer halt in the retreat of the ice front than any other in the quadrangle, a halt that gave time for a large accumulation. Unequal deposition of till about a mile south of California made a basin for a little pond shut in by the moraine, but it lasted for a short time only and was long ago filled by surface wash.

Two drainage channels, now abandoned, were made while the Powell moraine was being formed. One, a mile or more long, lies between Sunbury and Galena and was made by a marginal stream; the other extends nearly across the moraine north of Westerville and was the site of a stream until Alum Creek had cut a channel deep enough to rob it of water. Most of the drainage of the Columbus quadrangle while the moraine was being formed was restricted mainly to the present valley courses; nor did the streams lay down much waste during this substage, for only insignificant deposits occur in their valleys. Around Columbus are 10 or 12 square miles of outwash deposits of late Wisconsin age, most of which probably date from the Powell substage. The steep grade from the moraine

[1] Leverett, Frank, Glacial formations and drainage features of the Erie and Ohio basins: U. S. Geol. Survey Mon. 41, pp. 383, 405, 1902.

southward to a point near Marble Cliff on the Scioto and to Clintonville on the Olentangy prevented deposition, whereas the lower grade for some distance farther south encouraged it.

Later Wisconsin time.—After building the Powell moraine the ice finally melted from the quadrangle, depositing back of the moraine a level, even-surfaced till sheet, as in the other intermorainic areas. Its retreat across northern Ohio, as in the Columbus quadrangle, was interrupted by halts and short advances, each marked by a recessional moraine. After it had left the plateau a lake—glacial Lake Maumee—was formed between the ice front and the escarpment and discharged southwestward into Wabash River. Then followed the glacial lakes that successively occupied the basins of the Great Lakes, until finally the ice disappeared from the drainage basin of the St. Lawrence, an event which is generally regarded as marking the close of the Pleistocene epoch in North America.

During the melting of the Wisconsin ice the streams that began flowing as soon as the surface of the quadrangle was uncovered were at work stripping the surface of loose material, forming their valleys, and adjusting themselves to the conditions that they found. The Wisconsin ice sheet had blotted out the former drainage lines and had left over the region a till sheet having a fairly even surface, diversified, however, by five somewhat concentric moraines, several kames and eskers, and many details of ice and water work. In spite of erosion and deposition by the ice the features peculiar to the three main topographic divisions of the quadrangle still persisted and, together with the unevenness of the surface of the drift, served to direct much of the initial postglacial drainage. Upon such a surface and such material—generally loose deposits of heterogeneous composition and irregular thickness, with hard rock just beneath—the present streams began flowing and the area again became subject to normal stream erosion.

RECENT EPOCH.

Drainage development.—In the Columbus area no noticeable change in conditions marked the transition from Pleistocene to Recent time. The ice had left the area long before and the present drainage system was already well developed.

As a rule the courses of the streams are consequent on the topography as the Wisconsin glacier left it. Probably none but the Scioto below Columbus follows an earlier valley and even there the old valley is much too large for the stream, whose present flood plain occupies no more than one-third or one-fourth of it. Little Walnut Creek also wanders for some miles through a part of the old "Newark River" valley. The courses of some streams are determined in part by moraines, as, for example, those of Walnut Creek above Galena and of Blacklick Creek above Havens Corners. Scioto Big Run took a normal course down the long, gentle, drift-mantled slope of the "Newark River" valley, as did other smaller streams south of it, but its course lies in a belt of very thick drift in an area of somewhat morainic topography. Walnut Creek flows for 18 miles south of Galena close to the foot of the westward-facing slope of the highland belt, in a course determined by the ice when it still lay near on the west.

While the ice front was retreating across the quadrangle some of the streams flowing from it had divided channels, as stated in a previous paragraph. Other divided channels, such as those south of Grandview and along the Scioto south of the cemeteries, are due to aggradation. As the streams ceased to aggrade or lost their heavy burdens they began to cut down, and of two divided channels that one which was deepened more rapidly soon took the water from the other, leaving an abandoned channel. Renick Run and a small tributary of Scioto Big Run flow in such courses. Others are shown on the surficial-geology map.

As the main valleys were deepened the drainage down their slopes started a fringe of subsequent lateral valleys, which are well-marked features along Scioto and Olentangy rivers in the northern part of the quadrangle. Lateral valleys are also developed in the southern part, but as the main valley there lies so little below the till plain they are still shallow and are less conspicuous. While these lateral valleys were being developed both alluvial and rock terraces were being cut along Scioto (see Pl. III) and Olentangy rivers and to a much less extent along Alum and Darby creeks.

The multiplication and growth of lateral valleys have brought about dissection of the till plain. The valleys have been widened and tributaries to them have been cut and then lengthened by headward erosion until a large part of the till plain has been dissected by the streams. Hundreds of square miles, however, yet remain almost unmodified by erosion.

Waterfalls that were formerly at the mouths of several of the tributaries of the Scioto have retreated up their valleys, some only a hundred feet or so, others a thousand feet or more. In Indian Run, emptying at Dublin, a single fall was formed, which retreated half a mile up the run to the junction of the two forks, where it divided, and each fall has now migrated some little distance farther up.

Little flood plains have been formed at many levels as the streams have cut down and at the same time have slightly widened their valleys. Where the lateral erosion is slight the flood plains are meager. The present valley floors are broader than previous ones. Earlier valley floors and flood plains are left as terraces a little above the stream as downcutting proceeds, then lateral planation trims up the fronts of the terraces, or entirely removes them, building broader plains at a lower level. Only along the major streams and a few of the larger tributaries are the present flood plains broad enough to be mapped. Upon the plains at the mouths of most of the tributaries waste has been deposited in the form of fans, some simple, others compound. Some of the tributaries, as their grade is being reduced, are beginning to dissect their fans. Here and there a large stream of low grade has built a broad fan and a more recent smaller one has built a steep fan upon it.

Changes on the till plains are still going forward, even where headward erosion has not begun to modify them. The fine material is being washed from swells and hummocks into the sags, which are thus being filled. Kettles that once held small ponds are now swamps or are drained and under cultivation.

By all these changes valleys have been developed to rather advanced youth over much of the till plain. More mature stages of development have been reached along the main streams or those working in drift, but large parts of the till plain still stand in the stage of early youth, untouched by streams.

Relations of topography and culture.—The untouched remnants of the till plain form excellent farming lands and have been appropriated to agriculture. Because of their incomplete drainage they have been underdrained by tile, made largely from the abundant glacial drift. This underdrainage checks further stream development.

The slopes of the main valleys, especially the younger slopes of the lateral valleys, are largely given over to timber or to pasture. The flood plains are mostly under cultivation, and near Columbus they are much used for gardening.

The steep rock bluffs of the Scioto and many of its tributaries lay bare the Columbus limestone and make quarrying easy, and the industry has had a remarkable development around Marble Cliff in recent years.

Columbus, the only city in the quadrangle, was founded on the pleasant, well-drained, gravelly bluffs of the Scioto at the two big bends below its junction with the Olentangy. The city has spread northward and southward along the rivers more than 8 miles and eastward across the higher interstream area to and beyond Alum Creek. It grew westward over the broad gravelly flood plain in spite of flood dangers, and in recent years has spread over the high interstream area between Olentangy and Scioto rivers. Easy railroad communication has helped to make it a commercial center, and the well-populated rich agricultural lands around it have produced large quantities of grain and cattle for local consumption and have furnished a good market for local manufactures.

ECONOMIC GEOLOGY.

The mineral resources of the Columbus quadrangle include limestone, sandstone, clay, sand, and gravel, as well as water and soils.

LIMESTONE.

The limestone of the quadrangle ranks among the most important in the State and is suitable for a variety of purposes. Large quarries extend along Scioto River from the vicinity of the Central Hospital northward to the storage dam, a distance of 4 miles.

Flux.—The Columbus limestone, which is used in a large way for flux, differs considerably in composition from place to place and from layer to layer. Thus the "bone bed" contains a large percentage of calcium phosphate, one analysis showing over 16 per cent. Probably an analysis of the basal part of the same layer would show less than one-tenth of 1 per cent. Its content of silica is low, ranging commonly from 1 to 4 per cent, both extremes being unusual. The iron and alumina generally make up less than 1 per cent of the rock.

The calcium and magnesium carbonates have a greater range, and as one increases the other decreases. The proportion of calcium carbonate is greatest near the top of the formation, where in some places it constitutes 96 per cent of the rock, and decreases irregularly with the depth to only 80 per cent in places.

The proportion of magnesium carbonate is lowest near the top, where it may be less than 1 per cent, and highest near the base, where it may exceed 16 per cent. These relations are well shown in the two following analyses, the first being that of the "gray rock" near the top of the formation and the second that of the "six-foot six" near the base of the quarry:

Composition of "gray rock."

Calcium carbonate	96.51
Magnesium carbonate	1.43
Silica	1.10
Iron and alumina	.70
Phosphorus	.04

Composition of "six-foot-six course."

Calcium carbonate	80.900
Magnesium carbonate	16.070
Silica	2.000
Iron and alumina	1.100
Phosphorus	.016

For use as flux in making pig iron the limestone must be low in phosphorus, silica, and sulphur. Not all the beds can be used for this purpose, and at present the upper limit is the "gray rock." All the beds of limestone below this layer are available for use as flux, though some of the beds are better adapted to this use than others.

Building stone.—The Columbus limestone is an important source of building stone, and is at present the only rock so used, though the sandstones of the Cuyahoga formation in the southeastern part of the quadrangle have in former years yielded some stone for that purpose. (See Pl. VII.)

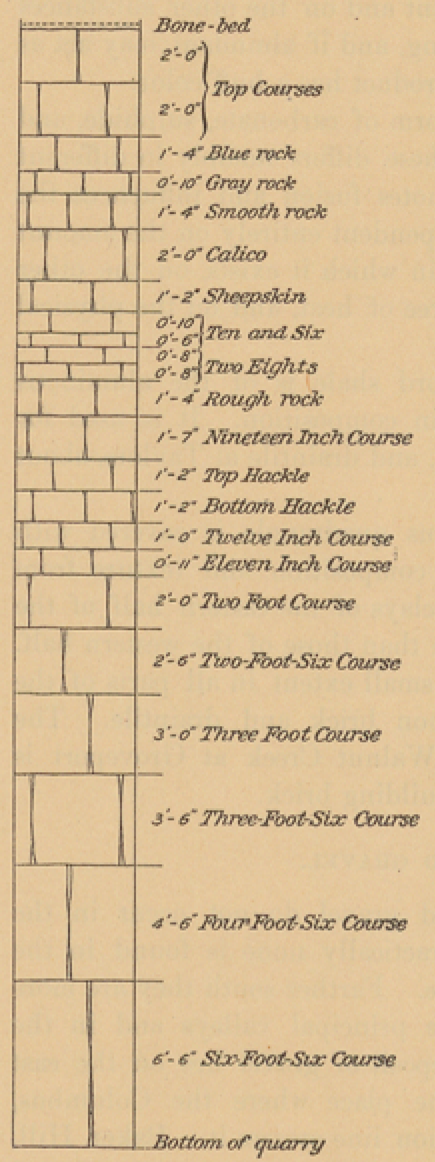

FIGURE 9.—Section of Columbus limestone at Marble Cliff quarry.

Showing the quarry beds and the names by which they are known at the quarry.

The rock is fairly even bedded, but the layers have a considerable range in thickness. (See Pl. IV.) Thus at Marble Cliff the range is from less than 1 foot to more than 6 feet, the thickest layers lying below. (See fig. 9.) The rock is strong, meeting in this respect the severest demands of the architect or engineer. The surface of different layers differs somewhat, giving rise to such names as rough rock, hackle-tooth, smooth rock, etc. Some of the rock is crystalline and takes a fair polish. In fact some of the beds were once thought to be marble, hence the name Marble Cliff. The color ranges from buff to blue, the buff predominating, but on exposure the shade may darken or become mottled.

Practically the whole of the Columbus limestone may be used as building stone. Naturally the thickest layers are best suited for massive structures and the thinner beds serve for foundations, caps, sills, and steps, and for use in ordinary structures, such as residences. The layers do not differ greatly in physical character, so that one works about as easily as another. The stone does not carve well. All in all the rock can not be classed as a first-rate building stone, except perhaps for massive structures like the statehouse, which is constructed of it, its appearance being rather unattractive, and it is losing favor except for foundations.

Paving stone.—The Columbus limestone is used in a very small way for flagging and curbing, and on a much larger scale in concrete sidewalks and as a foundation for street paving. The Delaware limestone also is used in making concrete and the limestone of the Monroe formation is suitable for this purpose.

Ballast and road metal.—The Columbus and Delaware limestones are well adapted for use as ballast on railroads and traction lines and are crushed in large quantity for this purpose. Both limestones are used also in constructing public highways. The Berea sandstone also is quarried and crushed for road making but in a small way. It is used for the bottom course and is covered with limestone.

Minor uses.—The Columbus limestone makes a good lime of the hot or quick-setting variety and was formerly burned on a rather large scale for this purpose. In fact it is now occasionally burned in a small way in the northwestern quarter of the quadrangle. Probably the lime-burning industry has declined because the stone can be used with more profit in other ways. The limestone of the Monroe formation also might be used for making lime, and as it is dolomitic it would yield a cool or slow-setting lime. The Columbus limestone is used also on soils and in the manufacture of glass and soda ash.

SHALE AND CLAY.

The shale and clay of the Columbus quadrangle are suitable for making bricks, building blocks, and draintile, and formerly the shale was used for making sewer pipe.

Ohio shale.—Although the Ohio shale may be used for making the more common clay products, such as brick, draintile, and sewer pipe, it is not well adapted for any of these uses. In composition it differs greatly within short distances in vertical section as well as areally, so that the product is hard to control in the kiln and the result is uncertain.

In many places it contains considerable carbon. The combustion of the carbonaceous matter during burning may under certain conditions produce too high a temperature, fusing the clay and of course warping the tiles or bricks. It also contains more or less sulphur, and in places it includes concretions of pyrite. The effect of sulphur depends largely on the way in which it occurs—that is, whether it is free or combined with other elements. It may appear on the surface of the finished product as a white coating that is unsightly and of course injures the market value of the product.

Calcium carbonate is another substance that is nearly everywhere if not everywhere present in the Ohio shale. In certain layers it forms a large part of the mass; in others it forms only a very small part or possibly is lacking. Its effects are various, depending in part on its amount and on the other substances present. It may promote fluxing, and if abundant may act as a bleaching agent, so that the product has a buff color.

The iron present is in the form of carbonate, sulphide, and oxide, and the proportion of these differs notably in different parts of the shale. Iron promotes fusion and influences the color, which, however, is not dependent entirely on the amount of iron, but also on the form in which it exists, on the other substances present, on the degree of heat, and on the physical state of the clay.

Bedford shale.—The Bedford shale is of the aluminous variety and is fairly uniform in composition. It is used for making bricks, building blocks, and draintile at Taylors, about 3 miles east of Columbus.

Glacial clay.—The Columbus quadrangle is covered with glacial clays, which differ in composition and texture from place to place. As a rule the clays of the eastern half of the quadrangle are of finer texture than those of the western half. The clays have been used to a small extent in all parts of the quadrangle for making common brick and draintile. The clay in the valley of Little Walnut Creek at Groveport is especially adapted to making building brick.

SAND AND GRAVEL.

Large deposits of sand and gravel do not occur in the vicinity of Columbus and practically none is found in the northern half of the quadrangle. Farther south they are more abundant, occurring along the principal valleys and in the interstream areas. A large deposit of gravel lies on the east bank of Walnut Creek at the place where the Columbus, Buckeye Lake & Newark traction line crosses it. Baker Hill, just south of Columbus, is essentially a mass of sand and gravel and much the same may be said of the hills on the Hartman farm, a few miles south of Columbus.

During the last few years the unique industry of dredging the channel of the Scioto for sand and gravel has been developed at Columbus. Two styles of dredges are used, one of which lifts the materials in buckets and the other sucks them up. Once on board the dredge the materials are screened, the finer forming sand and the coarser being marketed as gravel. Bowlders obtained in the dredging are crushed and mixed with the gravel. Gravel is probably used most extensively for road building, but it is employed also in laying walks and in making concrete and certain kinds of roofing in which tar is protected with a light cover of gravel. Sand is in large demand for making plaster and in cement work.

SEARCH FOR OIL AND GAS.

A persistent search for oil and gas has been made in the Columbus quadrangle. (See fig. 10.) Three wells in Columbus alone have penetrated the limestone of Trenton (?) age and a record of one of these follows:

Record of well bored in Columbus, Ohio, in search for oil or gas.

	Thickness in feet.	Depth in feet.
Glacial drift	148	148
Delaware limestone	32	180
Columbus limestone	100	280
Limestones of the Monroe formation and of Niagaran age	509	789
Limestone of Clinton (?) age	66	855
Shales, dark gray, unclassified	60	915
Approximate place of "Clinton" oil and gas sand	--------	915
Shales, brown, of Medina (?) age	67	982
Shales and limestones probably representing the Richmond, Maysville, Eden, and Utica	1,053	2,035
Limestone of Trenton (?) age	--------	2,035

In a test well sunk on the statehouse grounds drilling did not cease until a depth of 2,775 feet had been reached. This well showed that the lowest limestone listed in the above record is 475 feet thick. At least seven additional wells were drilled into the limestone of Trenton (?) age in the eastern half of the quadrangle, and one of them, on the Hartman farm, a few miles south of Columbus, reached a depth in excess of 3,100 feet. In none of these wells was either oil or gas found.

In addition to the wells which reached limestone of Trenton (?) age, at least six others have been sunk to the horizon of the "Clinton" sand (see fig. 10), but these also were failures. In fact it has been pretty definitely settled by the drill that this sand does not exist under the quadrangle.

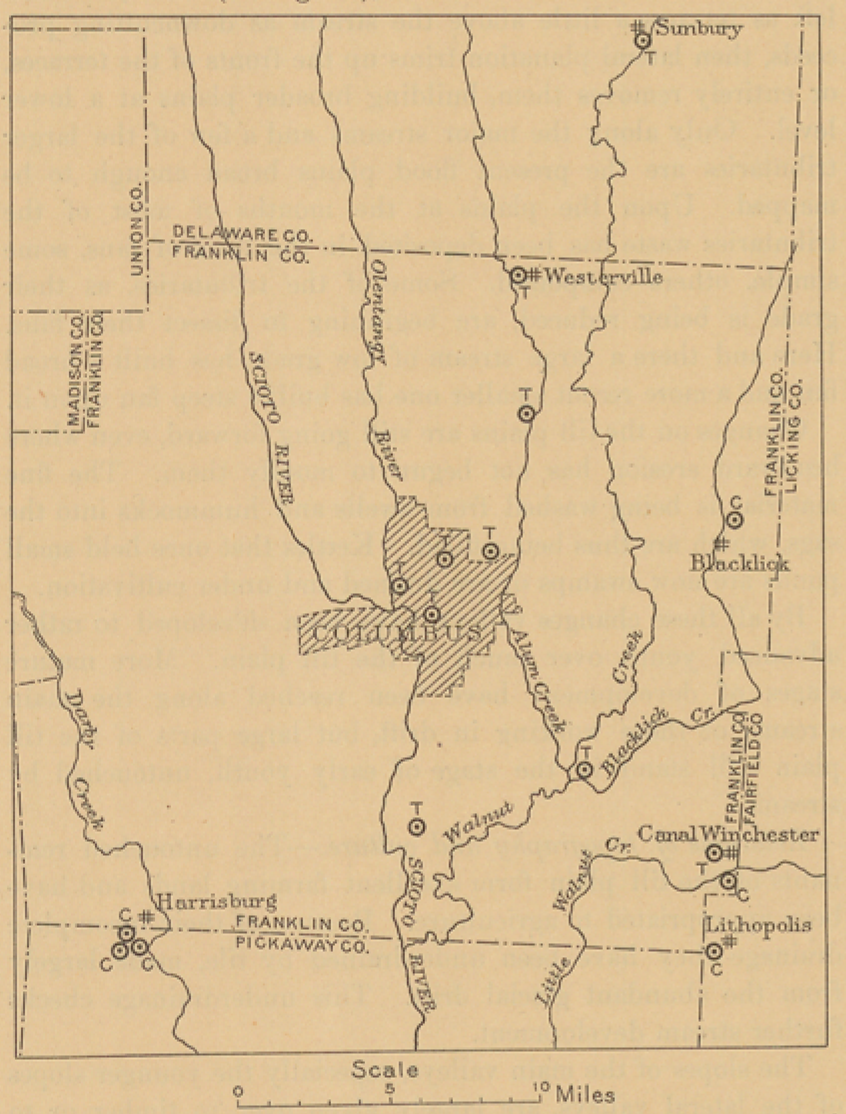

FIGURE 10.—Outline map of Columbus quadrangle showing location of deep wells drilled for oil and gas.

C, Wells that reach the "Clinton" sand; T, wells that reach the "Trenton" limestone.

WATER RESOURCES.

GROUND WATER.

The quantity of water stored in the ground depends not only on the precipitation, in the form of rain and snow, but also on the porosity, thickness, and structure of the materials on which the water falls or through which it percolates. In the Columbus area the surficial fine clay is almost impervious, but the coarser beds of sand and gravel are capable of storing and yielding large quantities of water. The limestones that underlie the western half of the quadrangle are also porous and are traversed by cracks, joints, and well-marked bedding planes and are capable of storing a large supply of water.

Except in a few small areas, mostly along streams, the surficial deposits are sufficiently thick to hold large volumes of water, but in many places they are too compact to permit water to enter, and wells in such places may give inadequate supplies. The depth at which sufficient water can be found differs greatly, even where the surface is flat or gently rolling. Wells in the drift around Columbus range in depth from 20 to 50 feet.

Many wells have been drilled by manufacturers in Columbus to a depth of more than 100 feet. They penetrate the limestone that underlies the drift and most of them yield large supplies. Water from such wells is generally very hard, and 16 analyses made in Columbus, equally divided between rock and drift wells, show that the water from the rock averages 27 per cent more of solid matter.

There are few flowing artesian wells in the Columbus quadrangle, though two large flowing wells near Harrisburg supply the farm of the Columbus Hospital for the Feeble-minded. One of these is shown in Plate VIII. The supply of water from these wells, which were drilled for oil or gas, is reported to have been struck at a depth of 550 feet. The water-bearing rocks rise to the west and are covered by an impervious layer of clay or shale, which affords artesian conditions.

Another artesian area is near the corner of East Eleventh Avenue and Summit Street, Columbus. Formerly water was found at a depth of a few feet in the drift and was encountered in excavating a number of cellars. So many wells were sunk, however, that the head has decreased.

Concerning the ground water of the Columbus area C. F. Long, analytical chemist, writes as follows:

The ground waters in and about Columbus are uniformly hard, as may be seen from the following table showing the results of tests. All the samples analyzed show alkalinities ranging from 242 to 468 parts per million. The amounts of incrustants, on the other hand, show greater variation, the range being from zero to 470 parts per million. The water from drift wells is somewhat lower in alkalinity or temporary hardness than the water from wells driven into rock. The amount of incrustants differs greatly, some waters from the drift exhibiting a total absence of the ingredients that form hard scale, whereas others from the same formation contain relatively large amounts. The water from wells drilled into the rock generally contains a large amount of incrusting constituents, ranging from 250 to 470 parts per million. The following table shows the mineral content of the water of several wells in and near Columbus:

Mineral content of water of wells in and near Columbus, Ohio.

[Parts per million; analyses by C. F. Long.]

Number.	Total hardness as $CaCO_3$.	Alkalinity as $CaCO_3$.	Incrustants.[a]	Magnesium (Mg).	Total solids.	Iron (Fe).	Free carbon dioxide (CO_2).
1	650	400	250	52	860	4.0	59
2	417	402	15	------	500	.7	38
3	812	342	470	73	1,552	5.0	24
4	257	242	15	------	285	10.0	10
5	808	468	340	73	1,296	4.2	70
6	382	382	None.	------	387	6.0	15
7	430	300	130	60	577	5.0	20
8	404	264	140	22	674	4.0	24

[a] Equivalent to permanent or noncarbonate hardness expressed as $CaCO_3$.

1. Statehouse; center of city; depth 80 feet, in rock.
2. Ralston Street Car Co.; east of city; depth 90 feet, in rock and drift.
3. G. E. Smith Shoe Co.; center of city; depth 80 feet, in rock.
4. C. Sohl; north end of city; depth 90 feet, in shale.
5. Bott Bros.; center of city; depth 80 feet, in rock.
6. C. R. Brown; north of city; depth 40 feet, in drift.
7. Excelsior Seat Co.; northwest of city; depth 50 feet, in drift.
8. Keever Starch Co.; south of city; depth 30 feet, in drift.

Springs are common, especially along Scioto River at places where it has cut through the limestone and thus made an outlet for the water stored in the rock. On the hills around Lithopolis there are many springs, a few of which are large. The water-bearing rock there is mostly sandstone containing but little soluble matter, and the water therefore carries less mineral matter than that obtained from most other sources in this quadrangle. The best known spring in the quadrangle is on the grounds of the Ohio State University. Its flow varies considerably and its supply probably comes from the drift rather than from the bedrock.

SURFACE WATERS.

The principal streams flow from north to south and their valleys as far as Columbus lie along somewhat parallel lines and are therefore separated by comparatively narrow areas. The streams south of Columbus converge toward Scioto River, which is the master stream of the quadrangle. This arrangement of streams provides a distribution of surface waters not commonly found in an area so small. The surface waters are not used for generating power, as the flow is frequently too small for such use.

Scioto River.—The drainage basin of the Scioto north of Columbus comprises about 1,060 square miles. The topography of this area is flat or gently rolling and the surface run-off is therefore slow as compared with that of the Muskingum or other streams that drain hilly parts of the State. The minimum measured flow of the Scioto at Columbus is 5 second-feet and its maximum flow in the great flood of 1913 was estimated at 80,000 second-feet. The stream was used formerly at several places for power, but the storage dam of the new city water-works has destroyed the opportunity for development of power immediately above Columbus. South of that city the Scioto has a broad flat plain and banks of drift, and damming the river is therefore more difficult; nevertheless, a mill was operated for years on the river at Shadeville.

Water supply of Columbus.—The water supply of Columbus is filtered and softened water from Scioto River, the new plant including one of the largest water-softening equipments in the world. A storage reservoir with a masonry dam has been built on Scioto River above the city. A new pumping station and the purification works were built about 4½ miles below the dam. The raw river water is raised at the purification works, is treated with lime water and a solution of soda ash, is thoroughly mixed, and is then subjected to sedimentation in six basins having a total capacity of 15,000,000 gallons. It is then filtered through ten rectangular rapid sand filters, each having a normal capacity of 3,000,000 gallons a day. The filtered water passes to two covered reservoirs, each having a capacity of 5,000,000 gallons. The daily consumption of water is about 15,000,000 gallons.[1]

The table on page 15 indicates the average mineral content and the range in mineral content of the water of Scioto River at Columbus. The yearly average is given for 1909, 1910, and 1911 and the monthly and yearly averages for 1912. According to serial tests made by the Ohio State Board of Health in 1897 the water of Scioto River at the Sandusky Street Bridge, Columbus, contained an average of 477 parts per million of total solids, of which 98 parts was volatile, and 7.2 parts per million of chlorine, and had a temporary hardness of 168 and a permanent hardness of 95 parts per million. The color of the water varied from 15 to 60 parts per million. According to tests made by C. P. Hoover, of the Columbus Water Purification Works, of 4 samples collected in the later half of 1909 the total mineral content of the river water ranged from 286 to 396 parts per million.

[1] Gregory, J. H., The improved water and sewage works of Columbus, Ohio: Am. Soc. Civil Eng. Proc., vol. 36, pp. 2-119, 587-622, 1910.

Average mineral content of the water of Scioto River at Columbus, Ohio.

[Parts per million; analyses by C. P. Hoover, Columbus Water Purification Works.]

Month (1912).	Color.	Turbidity.	Total hardness as $CaCO_3$.	Alkalinity as $CaCO_3$.	Incrustants [a]	Magnesium (Mg).	Free carbon dioxide (CO_2).
January	30	67	230	144	86	19	4
February	31	72	126	84	41	11	2
March	35	296	119	72	47	9.6	2
April	25	134	208	136	71	16	2
May	28	86	224	155	68	18	.0
June	33	160	189	133	56	15	.6
July	32	76	226	155	71	18	.0
August	36	46	210	149	61	16	.0
September	16	21	233	166	68	19	.0
October	24	27	245	163	81	21	.0
November	27	21	294	181	113	23	.0
December	18	10	357	212	139	31	.0
Average for 1912	28	84	222	146	75	18	.9
Average for 1911	28	68	245	150	95	21	.8
Average for 1910	29	37	270	158	113	23	1.1
Average for 1909	42	86	253	150	102	21	2.7

[a] Equivalent to permanent or noncarbonate hardness expressed as $CaCO_3$.

Olentangy River.—The Olentangy, which unites with the Scioto at Columbus, has a drainage basin of 520 square miles. Its minimum flow is about 5 second-feet and its maximum flow is estimated at 60,000 second-feet. The water was formerly used for generating power at several places in the quadrangle, and was a source of the water supply of Columbus. The stream is ponded at Olentangy Park (Columbus) for pleasure or recreation.

Other streams.—Alum Creek drains about 196 square miles. It was formerly used for generating power at several places and also as a source of water for Columbus. The stream unites with Big Walnut and Blacklick creeks in the southeastern quarter of the quadrangle. No use is made of the water of these two streams except by farmers.

SOILS.

General character.—The bedrock of the quadrangle is nearly everywhere covered with a thick mantle of surficial deposits, chiefly of glacial origin, so most of the soil consists of transported and foreign material. In spite of the thickness of the drift in most of the area, however, the soils contain considerable material derived from the underlying formations. The formations occupy belts having a general north-south trend and the ice moved southward over the area, so that a belt of till underlain by rock of any one sort contains considerable material that was derived from the underlying rock and merely carried southward a little way along the belt; and narrow belts of till along the line of contact of two formations contain mixtures of material derived from the two. Mingled with the material of local derivation is drift from northern Ohio and even some from Canada. All these elements have had a share in determining the character of the soils.

The soils of the quadrangle differ in history as well as in composition, as by no means all the soil is formed of unmodified glacial drift. In the valleys there are considerable areas of alluvial soils, deposited either along existing streams or along streams that flowed from the melting ice, and such soils are as a rule more fertile than those composed of unmodified till. Even on the upland areas, although there are no alluvial deposits formed by large streams, there has been more or less wash from higher to lower ground and a concentration of the more fertile elements of the soil in the slightly lower areas.

The fertility of soils and their adaptability to raising various crops depend in part on their physical character and in part on their composition, and both of these depend in turn on the material from which the soils were derived and on the amount of modification which they have undergone. The soils of different parts of the quadrangle therefore differ considerably in fertility.

Soils derived from limestone are in general more fertile than those derived from shale or sandstone because they contain a greater variety of the materials essential to plant growth. As a rule the limestone soils of Ohio are noticeably richer than those formed from sandstone or shale. This difference is well illustrated in the Columbus quadrangle, where the soils of the western half of the area, which is underlain by limestone, are distinctly more fertile than those of the eastern half, which is occupied by shales and sandstones.

Alluvial soils are, on the average, more fertile than most sedentary soils, because they contain a greater variety of materials and a larger proportion of organic matter. By the wash from higher to lower ground the finer, more soluble elements of the uplands are concentrated in a relatively small area of lowland. The soils of the valleys of the quadrangle are therefore richer than those of the uplands.

Sandy and gravelly soils, if not too stony, are generally more fertile than clay soils, because, being more porous, they are better drained, are less injured by long drought, and permit freer circulation of air. As a rule, too, they contain a greater variety of constituents. The soils of the southeastern part of the quadrangle consist largely of glacial outwash, and, although for that reason they are hardly so rich in organic matter as more recent alluvium, they are among the most fertile soils of the quadrangle.

Classification.—The soils of the quadrangle have been studied and mapped by the Bureau of Soils,[1] and the reports of that bureau contain the essential details regarding the distribution, thickness, and character of the several types of soils recognized by it in the area.

[1] U. S. Dept. Agr. Bur. Soils Field Operations, 1902, p. 403, and 1905, p. 715.

The greater part of the upland area of the quadrangle, about four-fifths of the whole, is covered by a clay-loam soil, formed of the weathered glacial drift. It differs greatly from place to place in character and fertility, which depend in part on the nature of the underlying rock and in part on the quantity of stratified drift it contains. The soil in the northeastern part of the quadrangle, where the drift is thin and the underlying rock is chiefly shale, is somewhat poorer than the average in plant food, and is a rather fine grained clayey soil, which packs too closely and is therefore not sufficiently permeable to air and water and suffers from drought. Such soils are improved by underdraining.

Numerous small irregular areas, which occupy slight depressions in the general surface and are scattered through the quadrangle, though more abundant in its southern part, are covered with a black clay loam. This loam is more fertile than the soil of the surrounding tracts and owes its color and its greater fertility chiefly to its content of organic material, in part derived from vegetation that grew on the areas and in part washed in from the higher land about them.

The terraces along the valley sides and a few outwash plains are covered with a gravelly loam, in which, however, the percentage of pebbles is not generally large enough to interfere seriously with cultivation. Most of the areas of this soil are in the southern half of the quadrangle, and some of them are above the average in fertility.

The flood plains, although formed largely of sand and gravel, are covered with a dark-colored fine silty or clayey loam, which is, on the whole, the most fertile soil of the quadrangle. Its color is due to the presence of organic matter. Lying as it does in the valley bottoms, this soil is subject to overflow by the spring floods, which, on the whole, do it more harm than good. Some floods renew its fertility by leaving a fresh deposit of silt, rich in organic matter or plant food; others wash away the finer alluvium or cover it with less fertile sand and gravel.

In summing up it may be said that, inasmuch as soils that overlie limestone are richer than those that overlie shale and sandstone, the soils of the western half of the quadrangle are on the whole more fertile than those of the eastern half. Furthermore, as the soils in the valleys are richer than those on the uplands and as alluvial soils are richer than those formed mainly of weathered till, the soils of the southern half of the quadrangle are rather better than those of the northern half. Finally, since the land lies lowest, the valleys are broadest, and the alluvial soils are thickest and most extensive in the southeastern part of the quadrangle, the most fertile soils are found in that part.

July, 1914.

TOPOGRAPHY

STATE OF OHIO
JUDSON HARMON, GOVERNOR.
C. E. SHERMAN, INSPECTOR.

U. S. GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

OHIO
COLUMBUS QUADRANGLE

Topography and control by U. S. Geological Survey.
Reduced from Dublin, East Columbus, West Columbus, and Westerville atlas sheets.
Surveyed in 1899, 1901, and 1902.

SURVEYED IN COOPERATION WITH THE STATE OF OHIO.

APPROXIMATE MEAN DECLINATION 1902.

Scale $\frac{1}{125000}$

Contour interval 20 feet.
Datum is mean sea level.

Edition of Aug. 1912, reprinted Dec. 1912.

U.S. GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

AREAL GEOLOGY

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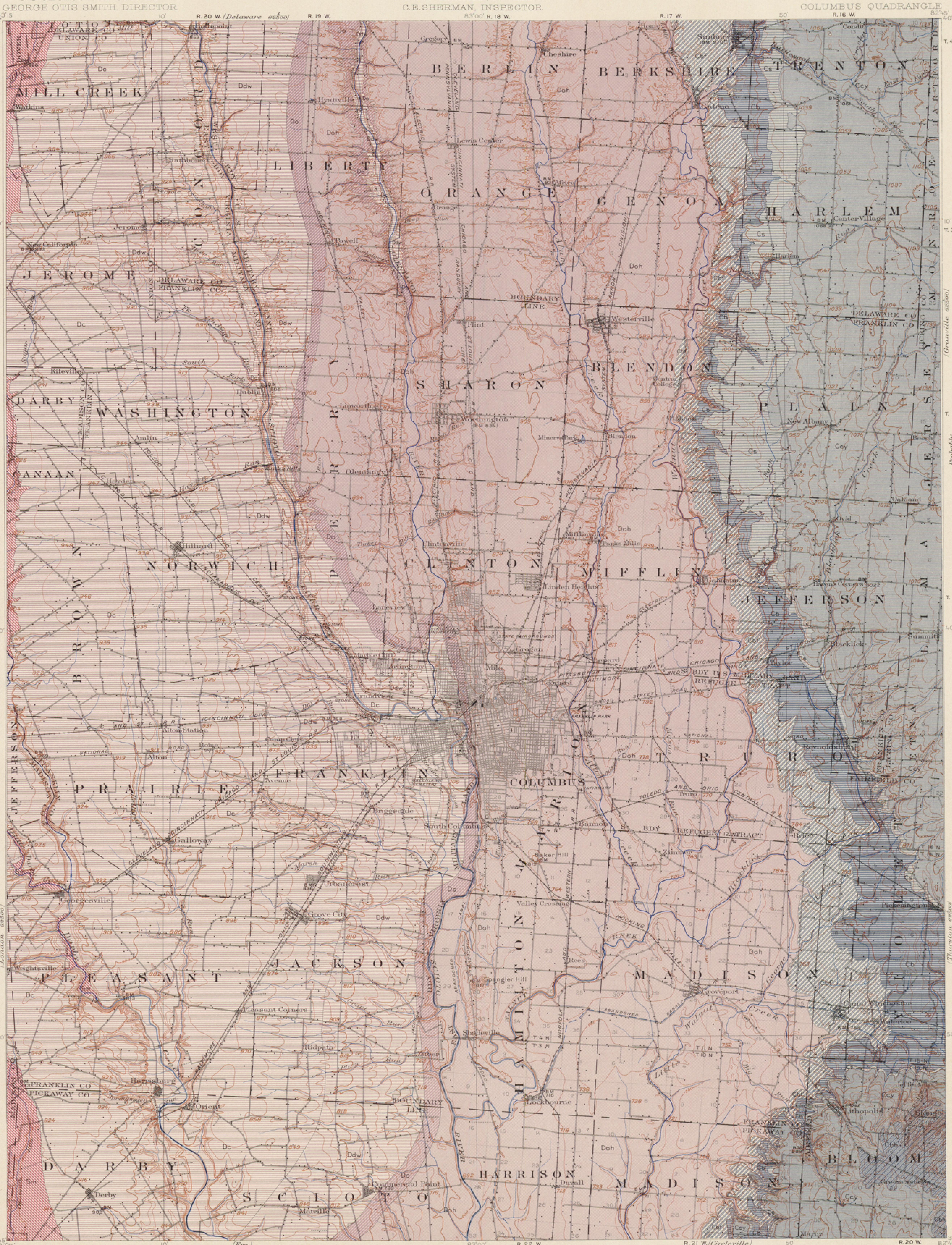
OHIO
COLUMBUS QUADRANGLE



LEGEND

SEDIMENTARY ROCKS

(Areas of subaqueous deposits are shown by patterns of parallel lines)

CARBONIFEROUS — Mississippian

- Cbh — **Black Hand formation** *(red to buff coarse sandstone)*
- Ccy — **Cuyahoga formation** *(bluish-gray argillaceous shale interbedded with fine-grained sandstone)*
- Cs — **Sunbury shale** *(black fissile bituminous argillaceous shale)*
- Cb — **Berea sandstone** *(fine-grained gray to buff sandstone)*

UNCONFORMITY

- Cbf — **Bedford shale** *(bluish-gray to red clay shale)*

DEVONIAN

Probably equivalent to Genesee, Portage, and Chemung formations

- Doh — **Ohio shale** *(bituminous black shale with large concretions)*

Equivalent to Marcellus and Hamilton shales

- Do — **Olentangy shale** *(soft blue calcareous and argillaceous shale)*
- Ddw — **Delaware limestone** *(blue cherty limestone and brown calcareous shale)*

Equivalent to Onondaga limestone

- Dc — **Columbus limestone** *(massive gray limestone, brown and magnesian towards base, with a basal limestone conglomerate)*

UNCONFORMITY

SILURIAN

Equivalent in part to Cayuga group

- Sm — **Monroe formation** *(compact drab banded limestone and much gypsum near the base not exposed)*

The rocks are largely concealed by glacial and alluvial deposits which are separately mapped on the Surficial-geology map

✕ *Stone quarry*

Note: *Columbus limestone yields material suitable for building stone lime, flux, ballast, and road making. Delaware limestone for ballast and road making. Olentangy, Ohio, and Bedford shales may be used for making tile, brick, and building block. Cuyahoga formation yields some building stone.*

Topography and control by U.S. Geological Survey.
Reduced from Dublin, East Columbus, West Columbus, and Westerville atlas sheets.
Surveyed in 1899, 1901, and 1902.

SURVEYED IN COOPERATION WITH THE STATE OF OHIO.

Scale $\frac{1}{125000}$

1 ½ 0 1 2 3 4 5 Miles

1 ½ 0 1 2 3 4 5 Kilometers

Contour interval 20 feet.
Datum is mean sea level.
Edition of Jan. 1913

APPROXIMATE MEAN DECLINATION 1902.

Geology by Clinton R. Stauffer.
Surveyed in 1906 and 1907.

SURVEYED BY THE STATE OF OHIO.
J. A. Bownocker, State Geologist.

SURFICIAL GEOLOGY

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JUDSON HARMON, GOVERNOR
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OHIO
COLUMBUS QUADRANGLE

LEGEND

SEDIMENTARY ROCKS

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

QUATERNARY

Recent

Qal — Flood-plain deposits and stream alluvium

Qat — Alluvium-covered rock terraces

Qaf — Alluvial fans *(simple and compound)*

Pleistocene *Wisconsin stage*

Qow — Outwash sand and gravel

Qlc — Lacustrine clay and sand *(deposited in small lakes at the margin of the ice sheet)*

Qe — Eskers *(ridges of sand and gravel)*

Qtm — Terminal moraines *(characterized by sag and swell topography, tumuli and kettles)*

Qk — Kames *(including ice-front ridges)*

Qgm — Ground moraine *(till sheet of yellowish boulder clay)*

Marginal escarpments of alluvial or rock terraces

Abandoned glacial and post-glacial drainage lines

Glacial striae

Note: Rock exposures too small to be mapped are numerous in the ravines.

Topography and control by U.S. Geological Survey
Reduced from Dublin, East Columbus, West Columbus, and Westerville atlas sheets.
Surveyed in 1899, 1901 and 1902.

SURVEYED IN COOPERATION WITH THE STATE OF OHIO.

Scale 1/62500

Contour interval 20 feet.
Datum is mean sea level.

Edition of Jan. 1913.

APPROXIMATE MEAN DECLINATION 1902

Geology by George D. Hubbard.
Surveyed in 1908-1910.
SURVEYED BY THE STATE OF OHIO.
J.A. Bownocker, State Geologist

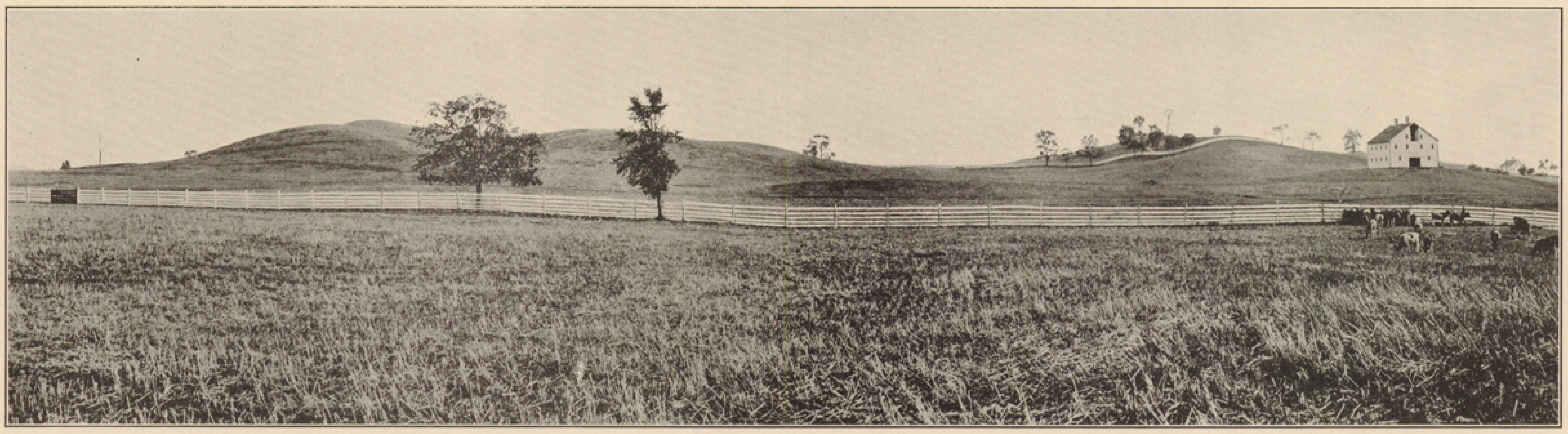

PLATE I.—KAMES OF SPANGLER HILL, 5 MILES SOUTH OF COLUMBUS.
Irregular hills of drift.

PLATE II.—SMALL GLACIAL-LAKE BED ON HARTMAN FARM, 5 MILES SOUTH OF COLUMBUS.
Looking southeast toward morainal hills in the distance.

PLATE III.—LEVEL SURFACE OF ROCK TERRACE OF SCIOTO RIVER AT MARBLE CLIFF.
Terrace was cut on Delaware limestone, fragments of which were used in building the stone fence in the foreground.

PLATE IV.—QUARRY FACE OF COLUMBUS LIMESTONE, NEAR MARBLE CLIFF.
Showing thicker-bedded quarry rock at the base.

PLATE V.—BEREA SANDSTONE RESTING UNCONFORMABLY ON BEDFORD SHALE, NEAR LITHOPOLIS.
The hard ledge above the man's head shows the full thickness of Berea sandstone present at this place. The nature of the unconformity and the variable thickness of the sandstone are clearly shown. (Photograph by H. A. Gleason.)

PLATE VI.—LARGE SPHEROIDAL "IRONSTONE" CONCRETIONS, CHARACTERISTIC OF THE LOWER PART OF THE OHIO SHALE, AT "THE NARROWS," NORTH OF WORTHINGTON.

PLATE VII.—QUARRY FACE OF LOWER PART OF CUYAHOGA FORMATION AT LITHOPOLIS.
Showing thick beds of homogeneous fine-grained sandstone suitable for building.

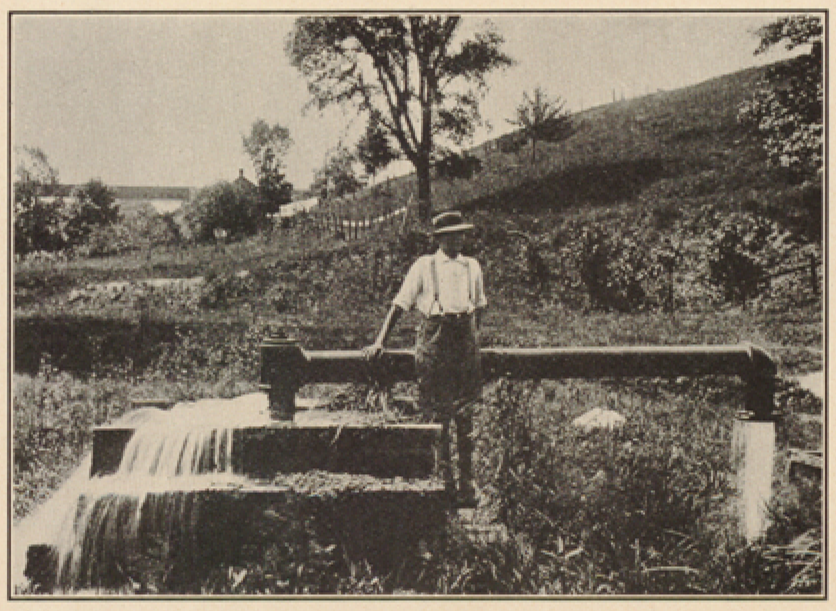

PLATE VIII.—FLOWING ARTESIAN WELL NEAR HARRISBURG.
Water obtained from Silurian limestone about 400 feet below surface.

LIST OF FOSSILS SHOWN ON ILLUSTRATION SHEET II.

Illustration Sheet II shows some of the fossils commonly found in the formations that outcrop in the Columbus quadrangle. The illustrations are taken from figures in other reports, chiefly those of State geological surveys, and are natural size except those otherwise marked.

FOSSILS FROM THE MONROE FORMATION (SILURIAN).

1. *Schuchertella hydraulica* (Whitfield). Enlarged 2½ diameters. Not positively known in central Ohio.
2, 3. *Spirifer ohioensis* Grabau. A rather rare fossil in this quadrangle.
4. *Greenfieldia whitfieldi* Grabau. Not positively known in central Ohio.
5. *Goniophora dubia* Hall. Not positively known in central Ohio.
6. *Leperditia altoides* Grabau. Enlarged about 2½ diameters. A very common fossil at certain horizons in the formation.

FOSSILS FROM THE COLUMBUS LIMESTONE (DEVONIAN).

7. *Favosites turbinatus* Billings. This compound coral is common in almost every section. Some of the larger specimens attain a diameter of 6 inches.
8. *Syringopora tabulata* Edwards and Haime. A large mass of closely set, straight corallites, having a convex upper surface; a common fossil.
9. *Cladopora robusta* Rominger. A rather common coral colony, which assumes the digitate form.
10. *Heliophyllum corniculum* (Lesueur). One of the most common cup corals of the upper portion of the formation. Most of the specimens are a little smaller than the illustration.
11. *Zaphrentis prolifica* Billings. A common coral.
12. *Zaphrentis gigantea* Lesueur. The largest of the cup corals and a characteristic fossil wherever the formation occurs.
13, 14. *Schizophoria propinqua* Hall. Common throughout the formation.
15, 16. *Chonetes mucronatus* Hall. Common in the Columbus limestone and also occurs in the Delaware.
17, 18. *Productella spinulicosta* Hall. Common in the Columbus limestone and also occurs in the Delaware.
19. *Pholidostrophia iowensis* (Owen). Common in the Columbus limestone and also in the Delaware.
20, 21. *Stropheodonta perplana* (Conrad). Common in the Columbus limestone and also occurs in the Delaware.
22. *Stropheodonta hemispherica* Hall. Common in the Columbus limestone and occasionally found in the Delaware.
23. *Meristella nasuta* (Conrad). A very characteristic fossil of the middle portion of the formation.
24. *Atrypa reticularis* (Linné). A common fossil of this and many other formations.
25. *Reticularia fimbriata* (Conrad). Not an abundant fossil, but many specimens are well preserved.
26, 27. *Spirifer gregarius* Clapp. A very characteristic fossil that occurs in greatest abundance a little above the middle of the formation.
28, 29. *Spirifer acuminatus* (Conrad). A very characteristic fossil of the upper portion of the formation.
30, 31. *Spirifer duodenarius* (Hall). Characteristic of the upper portion of the formation.
32. *Aviculipecten cleon* Hall. A rather rare fossil.
33. *Paracyclas elliptica* Hall. Occurs in both the Columbus and the Delaware limestones.
34. *Modiomorpha concentrica* (Conrad). A rather common fossil.
35. *Conocardium cuneus* (Conrad). A common fossil in the Columbus limestone but rare in the Delaware.
36. *Pleuronotus decewi* (Billings). A common fossil of the Columbus limestone and occasionally found in the Delaware.
37. *Platyceras dumosum* Conrad. Characteristic of the upper 10 feet of the formation.
38. *Callonema bellatulum* (Hall). Abundant in the cherty layers of the middle portion of the formation.
39. *Loxonema pexatum* Hall. Common in the middle and upper portions of the formation.
40, 41. *Bellerophon pelops* Hall. Common throughout the formation.
42. *Coleolus crenaticinctus* Hall. A rather rare fossil.
43. *Spiroceras thoas* (Hall). Not very abundant but very characteristic.
44. *Ryticeras columbiense* (Whitfield). Characteristic above the middle of the formation.
45, 46. *Phacops cristata* (Hall). Abundant in this formation.
47. *Chasmops calypso* Hall. Not abundant but characteristic.
48. *Proetus rowi* (Green). Abundant in this formation.
49, 50. *Coronura diurus* (Green). Rather common and very characteristic.

FOSSILS FROM THE DELAWARE LIMESTONE (DEVONIAN).

51. *Lingula ligea* Hall. Abundant in a zone near the middle of the formation.
52. *Lingula manni* Hall. Common in the 6 feet of brown shale forming the base of this limestone.
53, 54. *Orbiculoidea lodiensis* (Vanuxem). Commonly associated with *Lingula manni*.
55, 56. *Leiorhynchus limitare* (Vanuxem). A characteristic fossil of the Marcellus shale and common in the basal brown shale of the Delaware.
57. *Rhipidomella vanuxemi* Hall. A common fossil of the Delaware limestone and also occurs in the Columbus.
58, 59. *Chonetes deflectus* Hall. Common throughout the formation.
60. *Leptæna rhomboidalis* (Wilckens). Common throughout this formation and many others.
61. *Stropheodonta demissa* (Conrad). Common in this formation and also in the Columbus limestone.
62, 63. *Delthyris consobrina* (D'Orbigny). A common and very characteristic fossil.
64, 65. *Cyrtina hamiltonensis* Hall. A common fossil of the Delaware limestone and also occurs in the Columbus.
66, 67. *Martinia maia* (Billings). Abundant and very characteristic.
68. *Grammysia bisulcata* (Conrad). Characteristic of certain layers just below the middle of the formation.
69. *Pterinea flabellum* (Conrad). Found in both the Delaware and the Columbus limestones.
70, 71. *Platyceras erectum* Hall. A rather common fossil.
72, 73. *Tentaculites scalariformis* Hall. Common but not very characteristic.
74. *Phacops rana* (Green). A rather common fossil.

FOSSILS FROM THE BEDFORD SHALE (CARBONIFEROUS).

75, 76. *Paleoneilo bedfordensis* Meek. One of the most characteristic fossils of the formation, abundant at the base.

FOSSILS FROM THE SUNBURY SHALE (CARBONIFEROUS).

77. *Lingula melie* Hall. A common and characteristic fossil of the base of this formation.
78, 79. *Orbiculoidea herzeri* Hall and Clarke. An abundant fossil associated with *Lingula melie*.

FOSSILS FROM THE BLACK HAND FORMATION (CARBONIFEROUS).

These fossils are among the common forms in the Black Hand formation at Newark, east of the quadrangle, and are probably to be found in the same formation in the Columbus quadrangle.

80. *Allorisma winchelli* Meek.
81. *Allorisma convexum* Herrick.
82. *Sanguinolites naiadiformis* Winchell.
83. *Leiopteria ortoni* Herrick. Enlarged about 4 diameters.
84. *Crenipecten winchelli* (Meek).


FOSSILS FROM THE MONROE FORMATION.
FOSSILS FROM THE COLUMBUS LIMESTONE.
FOSSILS FROM THE DELAWARE LIMESTONE.
FOSSILS FROM THE BEDFORD SHALE.
FOSSILS FROM THE SUNBURY SHALE.
FOSSILS FROM THE BLACK HAND FORMATION.

and still smaller ones *stages*. The age of a rock is expressed by the name of the time interval in which it was formed.

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

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

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

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

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

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

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

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

Symbols and colors assigned to the rock systems.

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

SURFACE FORMS.

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

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

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

THE VARIOUS GEOLOGIC SHEETS.

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

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

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

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

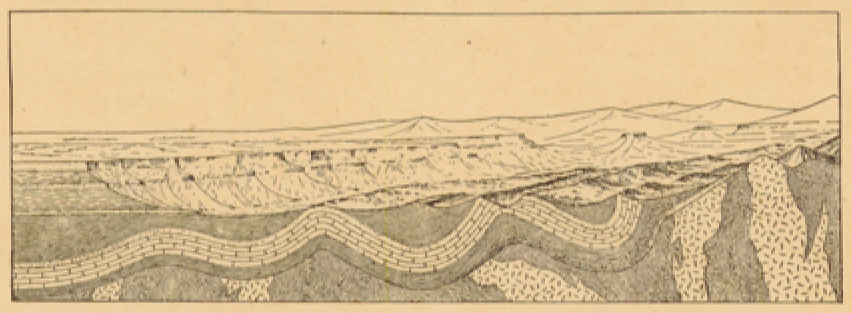

FIGURE 2.—Sketch showing a vertical section at the front and a landscape beyond.

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

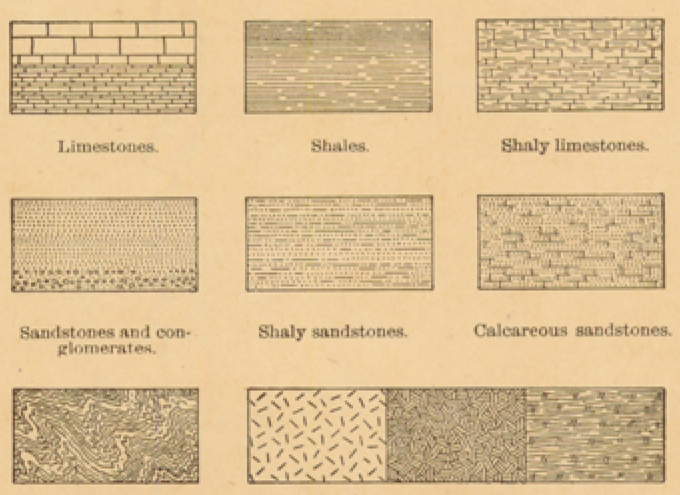

FIGURE 3.—Symbols used in sections to represent different kinds of rocks.

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

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

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

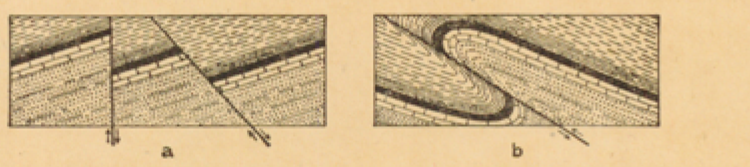

FIGURE 4.—Ideal sections of strata, showing (a) *normal* faults and (b) a *thrust* or *reverse* fault.

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

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

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

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

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

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

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

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

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

GEORGE OTIS SMITH,

Director.

May, 1909.

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