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UNITED STATES DEPARTMENT OF THE INTERIOR

# GEOLOGY AND MINERAL RESOURCES OF THE CLEVELAND DISTRICT OHIO

GEOLOGICAL SURVEY BULLETIN 818

UNITED STATES DEPARTMENT OF THE INTERIOR
**Ray Lyman Wilbur, Secretary**

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**George Otis Smith, Director**

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**Bulletin 818**

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# GEOLOGY AND MINERAL RESOURCES OF THE CLEVELAND DISTRICT, OHIO

BY

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AND
FRANK R. VAN HORN



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By H. P. Cushing, Frank Leverett, and Frank R. Van Horn[1]



## INTRODUCTION

By H. P. Cushing and Frank Leverett

### GENERAL RELATIONS

The Cleveland district, as described in this bulletin, lies in northeastern Ohio between the south shore of Lake Erie and parallel 41° 15′ and between meridians 81° 30′ and 82°. It comprises the Berea, Cleveland, and Euclid quadrangles, which have an aggregate land area of about 503 square miles. Nearly the whole of Cuyahoga County and small parts of Lorain, Medina, and Summit Counties are included in it. The city of Cleveland lies along the shore of Lake Erie in the northern part of the district. Adjoining it are several large suburbs, such as lie near to most flourishing cities. Berea and Bedford are villages 10 and 11 miles, respectively, from the city hall of Cleveland.

In its general geographic and geologic relations the area forms a part of the rather indefinite border zone in which the Appalachian Plateaus merge into the glaciated part of the Central Lowland, and it thus partakes somewhat of the character of both provinces, which are distinguished only by broad, general differences.

### GENERAL GEOGRAPHY AND GEOLOGY OF THE REGION

#### PHYSIOGRAPHIC DIVISIONS

Portions of two major physiographic divisions are included within the State of Ohio—the Appalachian Plateaus on the southeast and the Central Lowland on the northwest—each occupying about half the State. (See fig. 1.)

The Appalachian Plateaus include the large areas of hill land of southern New York, northwestern Pennsylvania, eastern Ohio, West Virginia, and eastern Kentucky. In northeastern Ohio the hilltops in this division range from 1,100 to 1,400 feet above sea level. The plateau is terminated on the north by the Portage escarpment, which

[1] Since the death of Professor Cushing, Prof. C. R. Stauffer has rendered valuable aid in mapping and Prof. J. E. Hyde has aided in the revision of the manuscript. Acknowledgment is also made for access to an unpublished manuscript on the Quaternary geology of the Cleveland district by Prof. Frank Carney. The description of the Quaternary here presented by Mr. Leverett is based on his own earlier and later studies.

is prominent and continuous from Cleveland eastward to Albany, N. Y. In the vicinity of Cleveland the escarpment that bounds the Appalachian Plateaus turns more to the south and passes between Columbus and Newark, through Chillicothe, and on southward into Kentucky. In the northern part of Ohio this escarpment is as high as the Portage escarpment, on the east, but its slope is more gentle and it is not so impressive. South of Newark it is bold and precipitous and is fully 300 feet high.


FIGURE 1.—Outline map of Ohio, showing physiographic provinces. The Cleveland district is shown by the shaded area. The numbers at the sides of the area indicate the three quadrangles: 1, Cleveland; 2, Euclid; 3, Berea

Northwest of the Appalachian Plateaus is the Central Lowland, which includes the lowland that surrounds the southern part of the Great Lakes and extends west as far as the border of the Great Plains. This region consists of rolling plains rather than hills, but its altitude in many places is equal to that of the Ohio part of the Appalachian Plateaus. In places the lowland is very hilly.

In the region of the lower Great Lakes the Central Lowland consists of a number of separate and distinct plains, which are known by the names Erie Plain, Huron Plain, and Ontario Plain. The lowest of these plains is the Ontario; this is separated from the Huron by a distinct rise or escarpment, and the Huron is separated by a similar feature from the higher Erie Plain. The sequence of terraces and escarpments can be carried farther, as the Erie Plain is separated from the generally flat top of the Appalachian Plateaus by the Portage escarpment.

The Erie Plain lies at the base of the Portage escarpment across western New York and extends along the prolongation of the escarpment across northwestern Pennsylvania and northeastern Ohio. It forms a large portion of the Ontario Peninsula between Lakes Huron and Ontario, and Lake Erie occupies a shallow depression in its surface. In New York the plain becomes very narrow east of Buffalo, and it pinches out against the Portage escarpment just east of Auburn.

From Buffalo to Cleveland the width of the plain between the shore of the lake and the escarpment is only a few miles, but west of Cleveland the escarpment swings away from the lake toward the southwest, and the plain broadens rapidly and increases in altitude. Within Ohio it ranges in altitude from 573 feet at the lake shore to nearly 1,000 feet. Its relief is slight, and it is on the whole a gently rolling, northward-sloping plain, interrupted only by morainic ridges and by the beaches and low cliffs of the glacial lakes.

Across western New York the Erie Plain is sharply separated from the Huron Plain by the low Onondaga escarpment. West of Buffalo, however, this escarpment becomes barely discernible, so that in Ontario the Huron and Erie Plains are practically merged into one. In Ontario in general the southwestern half of the triangular peninsula between Lakes Ontario and Huron belongs to the Erie Plain and the northeastern half to the Huron Plain. Westward across this peninsula the Huron Plain gradually rises and becomes higher than the Erie Plain, parts of it south of Georgian Bay being more than 1,500 feet above sea level.

The Niagara escarpment separates the Huron Plain from the Ontario Plain. East of Rochester these two plains merge into one by the disappearance of the escarpment, but at Rochester it is about 100 feet high, at Niagara about 200 feet, and it crosses the Ontarian Peninsula with steadily increasing altitude. It turns northwestward at Hamilton and continues to Georgian Bay, where, in the Blue Mountains, it has an altitude of more than 800 feet. Thence it crosses to northern Michigan, turns southward through eastern Wisconsin, and dies out in northern Illinois.

The Ontario Plain lies between the Niagara escarpment and the Laurentian Plateau. In New York its altitude ranges between 250 and 500 feet above sea level. Across Ontario the altitude increases and attains more than 700 feet south of Georgian Bay.

The Cleveland area includes the margins of the Appalachian Plateaus and the Central Lowland and the border zone between them. The larger topographic features are due to the bedrock surface and incised stream valleys, largely masked but not obliterated by the covering of drift left by the glaciers, and the minor features are due to glaciation and the action of glacial lakes. The northwestern two-thirds of Ohio, including the Cleveland area, was covered by the great ice sheets of the Pleistocene epoch; the southern boundary of the glaciated area crosses Ohio from the middle of the east side to the southwest corner of the State, running obliquely across plateau and lowland.

### DRAINAGE

The greater part of northern Ohio is drained to the St. Lawrence River and the remainder to the Ohio River. The Erie Plain is drained directly into Lake Erie, except that part lying east of Buffalo, which drains into Lake Ontario. The Ontario Plain is drained chiefly into Lake Ontario, but the western part drains into Lake Huron and the extreme eastern part into the Mohawk River.

The northern and northeastern margins of the Appalachian Plateaus drain into Lakes Erie and Ontario, chiefly through short streams that head not far back from the crest of the escarpment, through which they flow in deep, narrow valleys. The Grand River, in northeastern Ohio, is an exception, in that its valley across the escarpment is very broad. The Genesee River, in western New York, is a notable exception of another sort, as it rises in northern Pennsylvania far back from the escarpment and trenches it in a picturesque gorge. In northern Ohio the Grand, Chagrin, Cuyahoga, Rocky, Black, and Vermilion Rivers all rise not far within the plateau and flow north to Lake Erie. The greater part of the plateau in Ohio is drained southward into the Ohio River by means of streams that, in southeastern Ohio, occupy deep, narrow valleys; among these the Muskingum is chief. The Scioto and Miami, of central and southwestern Ohio, occupy much broader, shallower valleys. The divide between the drainage to Lake Erie and that to the Ohio runs rather close to the lake. It is inconspicuous and consists for the most part of low morainic ridges.

The preglacial drainage of the Appalachian Plateaus ran to the Erie Plain from all of eastern Ohio, northern West Virginia, and western Pennsylvania, a large part reaching it through the Grand River Basin. The drainage area of the Cuyahoga also extended farther south than at present. The change to present conditions came largely as a result of the glacial occupation. For a long time the glaciers wholly blocked the lower courses of many northward-flowing streams and forced them to seek outlets to the south. As the ice margin melted back from south to north the streams flowing southward filled up some of the northward-sloping drainage courses and dissected the surface sufficiently to divert much of the drainage into its present courses.

### STRATIGRAPHY AND STRUCTURE

The consolidated rocks of that part of the Central Lowland east of the Mississippi River and of the Appalachian Plateaus are, except a few small igneous dikes, wholly sedimentary and of Paleozoic age, ranging from Ordovician to Carboniferous. The Laurentian upland, north of Lake Ontario, is occupied by a complex of both igneous and sedimentary rocks of pre-Cambrian age, most of which are greatly metamorphosed. Similar ancient rocks extend everywhere beneath the region and form the floor upon which the Paleozoic rocks rest.

The stratified Paleozoic rocks have a general slight southward dip away from the area of ancient rocks. The oldest of them crop out around the border of the Laurentian upland, and on the south successively younger formations adjoin them in rudely concentric belts. The general southward dip is disturbed in places by broad, gentle folds. In western Ohio occurs the broad, low dome known as the Cincinnati arch, the axis of which trends nearly north. The rocks dip gently away from this axis, westward into Indiana and eastward or southeastward into central and eastern Ohio. In western New York and Pennsylvania and northeastern Ohio the rocks dip southward, and their belts of outcrop have a general eastward trend. In central Ohio the trend of the outcrop belts has swerved to a northerly direction, with eastward dip, along the east flank of the Cincinnati arch. Just west of Cleveland the strata swing from the eastward trend of northeastern Ohio to the northerly direction of central Ohio. About 20 feet to the mile is a common rate of dip in these regions. Other slight swells of the strata exist, of less magnitude than the Cincinnati arch—too slight to require material modification of the statement that the general structure of eastern Ohio is monoclinal.

There is close agreement between the relief of the region and the surface distribution of the formations, the more resistant beds capping escarpments and steep slopes and giving rise to platforms, whose surfaces, together with the lower slopes of the escarpments, are occupied by less resistant beds. The Ontario Plain is occupied by Ordovician limestone and shale and early Silurian shale and sandstone. The Niagara escarpment is capped by a massive limestone of middle Silurian age, and the Huron Plain is occupied by late Silurian limestone and shale. The Onondaga escarpment is formed of the Onondaga limestone, of Middle Devonian age. The Erie Plain is formed on shales of Upper Devonian age, including also shales of probably early Carboniferous (Mississippian) age at and west of Cleveland. There the southward swerve of the formations causes discordance between the relief and the surface distribution of formations, so that at and west of Sandusky much of the surface of the Erie Plain is formed on Silurian and Devonian limestones.

The rocks of the Portage escarpment in New York are sandstones and shales of Upper Devonian age. In passing into Ohio successively younger and younger rocks are found at the crest of the escarpment, and in the Cleveland district the Sharon conglomerate, of early Pennsylvanian age, forms its capstone. Within Ohio the Appalachian Plateaus are formed of shales and sandstones of Mississippian, Pennsylvanian, and lower Permian age.

## GEOLOGIC HISTORY

Little is known of the pre-Cambrian history of the region, but at the beginning of the Cambrian it was a land area, and existed as such for a long time, so that erosion reduced it to a nearly even surface. During late Cambrian time it became submerged beneath the waters of a shallow, epicontinental sea, the first of a series of such seas that invaded and covered parts of the interior of North America in Paleozoic time. Frequent changes in the relative levels of land and sea shifted the position of these seas, changed their size and shape, and shifted also their connections with the oceanic basins. Climates altered from humid to arid and from warm to cool and the reverse, and a tremendously long and complicated history was recorded, many of the details of which have not yet been worked out.

During much of the Paleozoic era the region was covered by marine waters, and successive sheets of mud, calcareous mud, sand, and gravel were spread over the sea bottom. At times nonmarine deposits were formed, such as the delta sands and coals of the Pennsylvanian of eastern Ohio, or the gypsum and rock-salt deposits laid down in the salt lakes of the Salina epoch and now buried 1,800 to 2,000 feet beneath Cleveland. At other times the waters were largely or completely withdrawn and the surface was partly worn away, instead of receiving deposits. Many of the seas contained abundant marine life, which in the earlier seas consisted entirely of invertebrate animals. In some beds of the Ordovician, Silurian, and Devonian periods the calcareous shells of these creatures are so plentiful as to constitute the major part of the rock. Later in the era fishes appeared, as shown by their remains in the Cleveland shale, and plants flourished, which have been preserved in the coal seams of the "Coal Measures."

No locality shows a complete section of the known Paleozoic formations, because the seas alternated with land, leaving many areas without record of long passages of time. Everywhere deposition was frequently interrupted, and at times the surface deposits underwent erosion. When the sea returned and deposition was renewed the new beds were laid down on the worn surface thus produced, which remains as an evidence of the time interval between the two sets of deposits. "Unconformities" of this kind are found at several horizons. The one beneath the Sharon conglomerate, at the base of the "Coal Measures," is the most significant one exposed in Ohio. A much less conspicuous one occurs beneath the Berea sandstone.

The first of the Paleozoic seas overspread the region in the later part of the Cambrian period. In the Ordovician and Silurian periods the region was many times submerged. Early Devonian seas barely reached it, but the Middle Devonian sea was widespread over it. A late Devonian sea also existed in the region but did not lay down thick deposits. Early Mississippian seas succeeded that of the late Devonian. During the later half of the Mississippian epoch the region was above sea level, and its surface was planed off by erosion. The land was low, however, and the thickness of material worn away was moderate. On the irregular surface thus formed, early in Pennsylvanian time, a thick deposit of sand and gravel with thin beds of mud and of plant débris, indicating strong currents, perhaps rivers, was formed over the region; this material has consolidated into the Sharon conglomerate. It was followed by the formation of a great thickness of Pennsylvanian shales and sandstones, with beds of coal, over all of southeastern Ohio. The sea then withdrew altogether from the region, and there is no evidence that it has since returned to any part of it, except for a recent occupation of the basin of Lake Ontario.

The Cincinnati arch was developed at the end of the Ordovician period and existed as a low dome over a large part of western Ohio throughout the remainder of Paleozoic time, sometimes as a land area, sometimes as a shoal. When not submerged it separated the marine waters covering Ohio from those on the west.

In the final stages of the Carboniferous period the whole region was brought above sea level and much of it was greatly elevated. The uplift was accompanied by profound deformation of the rocks along the east side of the Appalachian Plateaus and the region still farther east, the strata being closely folded and more or less faulted. It was by this disturbance that the Appalachian Mountains were formed. The Appalachian Plateaus, lying immediately west of this belt of intense folding, were broadly uplifted with only gentle folding, which decreased in amount westward, so that as a rule the folds in Ohio are perceptible only on careful determination of the altitude of the beds in different places. The uplift and deformation that produced the great mountain system in the eastern half of the Appalachian province probably gave the surface of much of the remainder, especially of its northern part, a northwestward slope, with considerable altitude at the base of the mountains, diminishing toward the country now occupied by the lakes.

The Mesozoic era thus began with the region above sea level and undergoing erosion, and it has probably never since been submerged.

The surface sloped to the northwest or north, and the original streams must have flowed down this slope. Erosion was several times accentuated by renewed uplift of the land, accompanied by some warping or tilting of the surface, which influenced the courses of the streams. During the early part of the era the region remained undisturbed so long that the surface of the entire region, even of the mountains, was worn down to a comparatively featureless plain of low altitude, or "peneplain." The uplift next following, probably at the end of the Jurassic period, was accompanied by marked eastward tilting of the region now forming the Atlantic Coastal Plain, so that the sea has since repeatedly invaded it as far as the present "fall line," and, as part of the peneplain was also involved in the tilting, the streams flowed down these new slopes toward the southeast. These streams had a short route to the sea compared with those flowing northwest, and this enabled them to extend their headwaters back into the plateau at the expense of the other streams.

This uplift of the plateau was great enough to revive the streams, which at once began to deepen their valleys across the old peneplain and to reduce the general surface. This erosion interval was not, however, as long as the preceding one, so that only the less resistant rocks of the district were worn down to a new peneplain. All the region north of the Portage escarpment and west of the Adirondacks was so worn down, and the Erie Plain is the remnant of the peneplain then formed. A subsequent uplift again lowered the grade of the streams, and the Ontario Plain was worn down below the level of the Erie Plain. During the Tertiary period the streams of the northern part of the Appalachian Plateaus in all likelihood flowed northward and northwestward into trunk streams that occupied the Erie and Ontario Valleys.

During the Pleistocene epoch great ice sheets, four at least, successively invaded the northern part of the United States from the Canadian plains. One or more reached as far south as Long Island, southern Ohio, Indiana, and Illinois, central Missouri, and northeastern Kansas. Evidence of four such invasions has been obtained in the Mississippi Valley. In Ohio there is certain evidence for at least two of these invasions, but by far the greater part of the glacial deposits are those of the last, or Wisconsin glacial stage. The ice of this stage spread out from the Labrador Peninsula and in western Ohio reached well toward the Ohio River. In eastern Ohio the high land of the Appalachian Plateaus so blocked its course that it extended only 60 to 80 miles south of the Lake Erie shore. The general direction of the ice movement over the Cleveland district was southward. As the ice advanced across the region it removed much of the loose surface material and somewhat eroded the underlying rock, especially where the rock was soft shale, so that the basal ice became heavily clogged with rock fragments. When the ice melted away it spread a sheet of such material over the surface, most thickly over the depressions and valleys, so that the new surface was much smoother than the old.

A very prominent effect of the ice invasion upon the region was the modification of the drainage systems. Many valleys were filled with glacial deposits, some were deepened and widened by ice erosion, and northward-flowing streams were dammed by the ice or by glacial deposits and forced to seek new outlets southward. Divides were shifted, in places for long distances, and the directions of many streams were permanently reversed. Some of the new stream courses occupied old valleys but in reversed direction, such as the lower 50 miles of the Scioto; others followed wholly new routes, such as the Scioto above Marion. Many of the streams that follow new routes have since cut gorges with waterfalls where they enter the preglacial portion—for example, the Cuyahoga. Most of the cataracts and gorges of northeastern Ohio and western Pennsylvania and New York, Niagara among the number, have thus originated.

When the invading ice melted away its southern margin moved slowly backward. In doing so it uncovered, in the present Great Lakes region, the western and southwestern ends of several basins whose natural outlets are on the east. After the ice front had withdrawn within these basins, it acted as a dam to those streams that flowed into them from the south and caused their waters to form lakes. For a long period it prevented these lakes from using their present outlets and raised them to levels of much higher outlets. As the ice withdrew farther or readvanced it uncovered lower outlets or blocked them again, and the lake levels fell and rose in consequence. When the present outlets were uncovered by the melting away of the ice the lakes finally fell to the level of these outlets. Traces of the successive changes in level are preserved in a series of old beaches extending entirely around the Great Lakes, some of them several hundred feet higher than the present surface of the lakes.

As a result of the tremendous weight of the ice over a very great length of time the northern part of the continent was, at the time of maximum ice occupation, depressed several hundred feet below its normal position. As the ice melted away and the weight was lessened, the continent slowly arose—a greater amount in the north, where it had been weighted most. As a result the shore lines, which were once horizontal, are now higher at the northeast than at the southwest.

The ice withdrew from the lower St. Lawrence Valley before the rebound of the continent was completed and while the outlet from Lake Ontario was yet below sea level, thus permitting the ocean waters to come into Lake Ontario for a short time, but they were drained out as the further upward movement of the land mass brought the present St. Lawrence River above sea level. This was the last occupation of the Great Lakes region by ocean water.

### RELATION OF CULTURE TO GEOLOGY

On the comparatively level surface of the Central Lowland transportation routes are free to follow any desired direction at a minimum of expense. Railroads are generally laid out in straight lines between points, and the vehicle roads follow the section lines, usually 1 mile apart. These facilities for transportation together with the general fertility of the glacially deposited soils, have permitted a rather uniform distribution of a fairly dense population, such as characterizes the western half of the State of Ohio.

In the unglaciated Appalachian Plateaus in eastern Ohio, the surface is rugged, and the tops of ridges are from 200 to 400 feet higher than the floors of the valleys. Much of the surface consists of steep slopes, many with thin soils, and much of it remains forested. Railway routes must follow the valleys and, in passing from one drainage system to another, must overcome steep grades. They are more expensive to lay out and to maintain than those in the glaciated plains. Roads commonly follow either the valleys or the crests of ridges and are correspondingly crooked. Population is less dense and settlement more uneven than on the plains. On the other hand, the mineral wealth of the plateau is an incentive to settlement.

The northern part of the Appalachian Plateaus was covered by the Pleistocene ice sheets, and its valleys are largely filled with glacial deposits. Its surface is therefore less rugged than that of the unglaciated part of the plateaus, its soils are better and more uniform, and transportation routes are much less hampered by steep slopes, are usually independent of stream valleys, and are laid out in nearly straight lines between places.

The Appalachian Plateaus form a high rugged land barrier to east-west trade routes across Ohio, except those that traverse the low strip of the Erie Plain. The Erie Plain connects on the east with the Mohawk Valley lowland, separating the Adirondack highland from the Appalachian Plateaus, and these two lowlands form the only natural low-grade route north of the Gulf Coastal Plain between the Atlantic seaboard and the interior of the United States. The Lake Erie ports are consequently the natural points for transshipment of the coal of the northern part of the Appalachian Plateaus and the iron ore of the Lake Superior region. Largely because of the industries that have developed in this meeting ground of coal and iron, the Erie Plain is the most densely populated part of Ohio.

## TOPOGRAPHY OF THE CLEVELAND DISTRICT

By H. P. Cushing

### SURFACE FEATURES

*General character.*—The altitude of the surface of the Cleveland district ranges from 573 feet above sea level along the lake shore to 1,300 feet on the south margin of the Cleveland quadrangle, in Richfield Township. The Portage escarpment, which separates the Erie Plain from the Appalachian Plateaus, crosses the Eculid, Cleveland, and Berea quadrangles from northeast to southwest. The boundary between plateau and plain is not very sharp but forms a zone, in places several miles wide. As a rough approximation two-thirds of the district may be said to belong to the hilly plateau and escarpment and one-third to the plain. All three parts are notched by the Cuyahoga River, Rocky River and its branches, Euclid and Big Creeks, and Doan Brook, most deeply where these streams have cut into the plateau and escarpment.

The slope of the Portage escarpment from plateau to plain is not simple. In the Berea quadrangle it is a single slope descending from the plateau surface to the plain, but in the Cleveland and Euclid quadrangles this slope is interrupted by one or, in places, two minor platforms or terraces.

Three resistant sandstone formations in the rock section at Cleveland, separated by a varying thickness of weak shale, mark the surface of the Appalachian Plateaus and the two lesser platforms on the slope of the Portage escarpment. The uppermost and thickest of these sandstones is the Sharon conglomerate, of Pottsville (lower Pennsylvanian age. It is the youngest Paleozoic rock exposed in the quadrangles and is the capstone formation of the plateau across northeastern Ohio. A thickness of 150 to 350 feet of beds, chiefly shale, separates it from the Berea sandstone beneath, and 50 feet of shale lies between the Berea sandstone and the Euclid sandstone lentil at the base of the Bedford shale. Because of their resistance erosion has developed a terrace at the summit of each of these sandstones, and each terrace terminates in a steep front or low cliff. From the foot of these scarps gentle slopes run down to the surface of the terraces below.

*Appalachian Plateaus.*—The rolling uplands of the southeastern two-thirds of the region form the northwestern margin of the Appalachian Plateaus. The highest hills, whose altitude ranges from 1,150 to 1,300 feet, are more or less flat topped and are composed of the Sharon conglomerate. There is, however, only about 15 square miles of such territory, contained in a dozen separate areas, so that much of the rolling plateau surface is on the underlying shale. There are three such areas east of the Cuyahoga River—one in Warrensville, one near Northfield, and one in Boston, the last capping the Cuyahoga Valley wall and giving rise to the picturesque scenery of the "Boston Ledges." Eight of them lie west of the Cuyahoga River in the southwestern part of the Cleveland quadrangle, but only one is of much size, and four of the eight are very small. Two occur in the Berea quadrangle. Taken together these form all that remains within the quadrangles of this sandstone platform, the original surface of the plateau. The topographic prominence that rightly belongs to them has in many places been greatly subdued by heavy banking of glacial drift against their fronts and in the lower lands between them. Some of them stand out as prominent hills, 100 feet or more above the level of the surrounding territory, flat topped and steep fronted or surrounded by low ledges. Upon many the soil is thin and poor, and they remain largely forested. Between these hills the sloping surface is gently rolling from an altitude of 1,100 or 1,200 feet down to about 900 or 1,000 feet, whence the slopes descend more steeply to the valleys of the Cuyahoga and Rocky Rivers.

This region does not suggest a plateau, but southeast of these quadrangles the plateau surface is distinct and more nearly continuous. The margin of the plateau in the Cleveland region has been dissected by stream erosion until it has been reduced to long promontories projecting northward from the main area of the plateau, and outlying patches have been wholly separated from it.

*Portage escarpment.*—The Portage escarpment is the irregular slope 2 to 4 miles wide that descends from an altitude of 1,200 or 1,240 feet on the northwestern edge of the Appalachian Plateaus to 700 or 800 feet at the southeastern margin of the Erie Plain. It is irregular and discontinuous because of the large valleys cut into the plateau, and it bends away from its southwesterly trend into the walls of these valleys. Its upper, southeastern limit has the intricate outline of the dissected margin of the plateau surface; its foot, bordering the plain, is much more continuous and regular. Northeast of Cleveland, in the Euclid quadrangle, the Erie Plain is abruptly terminated immediately southeast of Euclid Avenue by the foot of the Portage escarpment, at an altitude of 680 to 740 feet. In the northern third of the Cleveland quadrangle the foot of the escarpment bends southward into the east wall of the Cuyahoga Valley. West of the Cuyahoga River the southern margin of the Erie Plain or the foot of the escarpment, is not so sharply defined. Where the west wall of the valley bends westward into the escarpment, across Independence Township, it lies along Rockside Road, at an altitude of about 800 feet. Across Parma Township the margin may be regarded as bending southwestward at an altitude of either 800 or 880 feet, depending on whether the low Berea scarp (see p. 13) is included or not.

In the south-central part of the Berea quadrangle the Portage escarpment assumes the southerly trend that carries it entirely across Ohio, Kentucky, and Tennessee. The northern and western three-quarters of the quadrangle lie within the Erie Plain. The foot of the escarpment runs east of Berea, crosses the East Branch of the Rocky River near Strongsville, and runs east of the West Branch at the south line of the quadrangle. It is obscure in places but has an altitude between 800 and 900 feet.

The greater part of the Portage escarpment is made up of the long, gentle slopes of shale that descend from the Pottsville to the Berea terrace, or roughly that part of the Cleveland and Euclid quadrangles lying between 900 and 1,150 feet in altitude and of the Berea quadrangle between 800 and 1,150 feet. The general direction of the slope is northwest, but it is not sharply separated from the slopes of the valleys crossing the escarpment. There is some dissection by narrow, shallow stream valleys, but otherwise the slope is fairly uniform, descending from 40 to 80 feet to the mile and mantled everywhere with glacial drift. Rock outcrops are found principally in the stream valleys, and by no means in all, as many streams flow for miles in channels that nowhere cut through the drift.

The outcrop of the Berea sandstone makes a minor escarpment 30 to 50 feet high, which may be called the Berea scarp and which extends across the Euclid and Cleveland quadrangles in a southwesterly direction as far as the Cuyahoga Valley, where it swings to the south as a well-defined bench along the valley wall. As such it continues to the south margin of the Cleveland quadrangle, with a steady decrease in altitude, which brings it down to the level of the river about 3 miles farther south. There is a companion terrace on the west side of the valley. West of the Cuyahoga the Berea scarp continues westward and southwestward to the Rocky River at Berea, but the Berea sandstone declines in altitude, and the scarp is an obscure gentle slope of about 50 feet in a mile. At Berea the Berea sandstone descends below the level of the Central Lowland or Erie Plain and exerts no influence on the topography of the plain from Berea 13 miles westward to Elyria, in the Oberlin quadrangle, where it is again effective.

East of the Cuyahoga River the Euclid sandstone is present 50 feet below the Berea and caps part of a well-defined slope and terrace, the first rise of the Portage escarpment above the Erie Plain. West of the Cuyahoga Valley the Euclid sandstone and its terraces are absent, except for a small elevated area between 780 and 800 feet in altitude on the southern edge of the plain, in Brooklyn Township.

East of the Cuyahoga River the Portage escarpment forms three distinct steps, the first from 100 to 150 feet above the Erie Plain, largely under the influence of the Euclid sandstone; the second 50 feet higher and half to three-quarters of a mile south, the Berea sandstone; the third about 300 feet higher, 3 miles farther south and obscurely defined at the position of the Sharon conglomerate, at the edge of the Appalachian Plateaus.

West of the Cuyahoga River the Portage escarpment is not so high as on the east and consists of a single rise steeper than that east of the river, with the obscure Berea platform at its base.

Glacial deposits so thoroughly mantle the surface and clog the old valleys of the plateau and the escarpment slope that the present topography is much less varied than that which would be disclosed by the removal of these deposits. The plateau was deeply trenched by many old valleys, and its topography was much more rugged than it is now. It was a topography of mature stream dissection, in strong contrast to the present immaturity.

Two low morainic ridges, the Cleveland and Euclid moraines, slightly diversify the smooth slopes of the plateau and plain. The most westerly place at which the Cleveland moraine is recognizable as a distinct topographic feature is near Linndale, whence it runs to Brooklyn, following a course not far south of the valley of the main trunk of Big Creek. It is 20 to 30 feet high and about three-quarters of a mile broad. It is interrupted by the Cuyahoga Valley, but it reappears at Newburg, where it shows a number of knolls of gravelly drift, and continues east to Randall, where it joins the Defiance moraine and thence continues to the edge of the Cleveland quadrangle and beyond. In this part of its course, however, it is so low and so broad that its topographic expression is very indistinct. It is not mapped between Newburg and Randall.

The Euclid moraine shows only its west end in the Euclid quadrangle, just east of Euclid, as a thin mantle of till in a gentle ridge lying along the terrace at the top of the lowest or Euclid scarp. The terrace is not capped by the Euclid sandstone at this place. The Euclid moraine is noteworthy here as marking the west end of a series of moraines that follow the lower slopes of the Portage escarpment to the east end of Lake Erie, have much to do with the present configuration of the escarpment, and exert a profound influence upon the drainage of northeastern Ohio.

*Erie Plain.*—A considerable part of the Erie Plain is submerged beneath the waters of Lake Erie. Out in the lake is a channel of moderate depth that is probably best regarded as cut below the level of the plain, but with this exception the entire lake is shallow, and the bottom belongs with the Erie Plain. East of the Cuyahoga that part of the plain above the lake is only 2 to 3 miles wide and reaches the foot of the escarpment at an altitude of 700 feet at Euclid and 740 feet at Cleveland. The surface has a lakeward slope of 50 to 60 feet to the mile but is very smooth, except for the abandoned lake strands described below. The streams flow across it in shallow valleys that are deepest near the escarpment. The brook valleys are cut in the plain to depths of 10 to 40 feet, and the rivers run 40 to 100 feet below its level.

West of the Cuyahoga River the escarpment of the Euclid sandstone is absent and there is no sharp southern limit to the plain. Between the Cuyahoga and Rocky Rivers the plain may be regarded as from 4 to 5 miles broad and as rising from the lake cliffs to an altitude of about 800 feet. West of the Rocky River its breadth increases to 17 miles. Here also its slope to the lake is more gentle—approximately 20 feet to the mile. The surface is very even, except where varied by shallow brook valleys and low lake ridges.

The shore line of Lake Erie at most places is a steep or vertical wave-cut cliff from 30 to 50 feet high, broken only by the stream valleys that come down to the lake. Sand beaches are few and small. Much of the wave-cut shelf at the foot of the cliff is under water and impassable; where it is above water it is narrow. The shore line is fairly straight, and the storm waves sweep strongly against it. The cliff is composed of weak material, in places till or sand, in places shale, and the recession is moderately rapid, especially in the till or sand. In front of Cleveland, where the cliff consists of sand and lake clay, the recession was especially rapid until checked by driving piles and more recently by expensive breakwater construction. Deltas can not accumulate at the mouths of the streams. Bars form in front of the streams, but the bulk of the discharged material is carried alongshore by the current and distributed as offshore sand bars.

On the broad expanse of the Erie Plain, west of the Rocky River, are three low ridges, locally known as North, Middle, and Butternut Ridges. These ridges are roughly parallel to one another and to the lake shore but diverge slightly westward. They are plainly shown on the topographic map of the Berea quadrangle. Their crests rise from 10 to 30 feet higher than the surface of the plain just north of them, and from the crest of each there is, in many places, a gentle back slope to the south, dropping from 3 to 5 feet. These features are beach ridges formed at higher stages of Lake Erie, as explained under "Geologic history" (pp. 98–99).

The crest of Butternut Ridge has an altitude of 760 to 780 feet across the Berea quadrangle, except where it is interrupted by the Rocky River Valley. East of Linndale it abuts against the north side of the Cleveland moraine. East of this point it is hard to trace and has no importance as a topographic feature.

Middle Ridge lies from 1 to 2 miles north of Butternut Ridge. Its crest is at about 730 feet, about 40 feet lower than that of Butternut Ridge. Its course is interrupted by the Rocky River Valley and by the great trench of the Cuyahoga Valley. It is present between the

Rocky and Cuyahoga Rivers, where Dennison Avenue follows its crest. In the eastern part of Cleveland it lies just in front of the base of the escarpment, with its summit at about 730 feet. In the Euclid quadrangle it disappears as a ridge because the base of the escarpment drops to 700 feet and the level of the ridge is therefore about 30 feet up on the steep slope of the escarpment, where a ridge could not be developed. Here, a closely related topographic feature is found in a distinct platform from 100 to 150 yards in width, cut into the face of the escarpment about 40 to 45 feet above its base, and just south of Euclid Avenue.

North Ridge is about 3 miles north of Middle Ridge at the west margin of the Berea quadrangle and only half a mile north of it at the east margin. It is the only one of the three ridges that is continuous and strong entirely across the Cleveland and Euclid quadrangles except as it is interrupted by the Rocky River and Cuyahoga Valleys. Through the western part of Cleveland Detroit Avenue follows it rather closely; on the east side Euclid Avenue continues with it to Fortieth Street. Thence to a point east of Doan Brook it lies north of Euclid Avenue. East of Doan Brook this shore line is not a ridge but a wave-cut cliff, which forms the foot of the Portage escarpment and is followed very closely by Euclid Avenue to the east boundary of the Euclid quadrangle. The crest of this ridge or base of the cliff, as the case may be, is at about 680 feet—about 50 feet lower than Middle Ridge and cliff.

These beach ridges or cliffs, formed at higher stages of Lake Erie, are not the only ridges of the same type that occur within the quadrangle, but the others are too faint and too much interrupted to be notable topographic features.

*Valleys.*—The valleys of the quadrangles are of varied topography according as they do or do not coincide in location with old preglacial valleys. There are three types of stream valleys—old valleys, new valleys, and those that are part old and part new. Of the last-mentioned type there are two subtypes—those in which the lower part of the valley is old and the upper part new, and those in which the lower part is new and the upper part old. Within these quadrangles the Cuyahoga is the only stream of the first type, but the river enters its old valley 10 miles south of this area, and all its upper course is new, so that its valley as a whole belongs to the first subtype of the third group. The Rocky River is an excellent example of the second subtype, and Tinkers Creek is another. Euclid Creek and Big Creek flow in wholly new valleys.

The Cuyahoga Valley was partly filled with sand and silt in ponded glacial waters. Some of this filling has been cleared away by the river, and to an observer looking across from the summit of either valley wall, a broad and fairly deep valley is open to view bordered on both sides by prominent flat terraces 140 to 160 feet above the stream and 100 or 150 feet below the less prominent Berea terrace. The stream is not hampered by resistant rock, and its valley across the quadrangle is well graded. There are no falls and rapids in its course, and it has no gorge. The whole valley is evenly and broadly opened down to the level of the Berea terrace, and below that level a narrower inner valley has been cut. The rock walls of the valley descend with moderate gradient to the level of the Berea terrace, then more steeply to the level of the glacial silt terraces, and pass beneath them. The surface of the Berea terrace is much dissected by streams and descends upstream. That of the silt terraces is very level, with a gentle slope toward the center of the valley and a slope down the valley of about 7 feet to the mile. Its altitude is 800 to 820 feet at the south edge of the Cleveland quadrangle and 700 to 730 feet in the southern part of Cleveland. This terrace is divided into separate patches by the trenches which the river and its tributaries have cut into it. The river flows through it in a sinuous trench from 100 to 140 feet deep and from a quarter to half a mile wide. The swinging

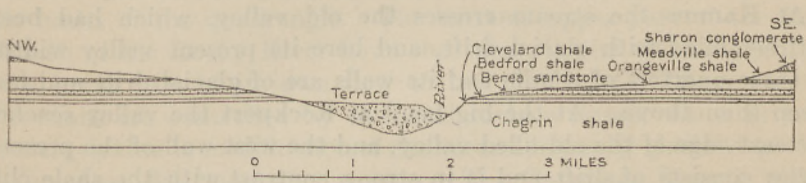


FIGURE 2.—Section across the Cuyahoga Valley from Walling Corners to Macedonia. Modern channel is shown at east side of old valley; terraced surface on glacial valley filling at the west

of the river carries the trench from one side of the valley to the other. Where it is against one of the rock walls of the valley, as at Boston, Brecksville, and Southpark, a broad remnant of the terrace lies between it and the other valley wall. (See fig. 2.) Where it is in a more central position remnants of the terrace may be seen on each side. At Southpark the river hugs the west wall, and the broad terrace on the east is cut squarely through by Tinkers Creek. At Brecksville the river flows against the east wall, and Chippewa Creek, coming in from the west, cuts across the terrace to reach the river. With its flat top and steep fronts this terrace forms a conspicuous feature all along the valley. The altitude of the terrace, 730 feet in the southern part of Cleveland, corresponds with that of Middle Ridge.

The valley of the Rocky River presents a strong contrast to that of the Cuyahoga. The upper part of its East Branch also follows an old valley, whose course across the Cleveland and Berea quadrangles is plainly shown on the geologic maps. In general appearance this part of the valley is like that of the Cuyahoga—broad and with high rock walls, though not so deep as the Cuyahoga Valley.

East of Strongsville the river forsakes this old valley, and thence downstream the valley has an entirely different character. Above Berea it is developed in a weak shale, is about a quarter of a mile wide, and is flat bottomed and bordered in places by nearly vertical walls of shale 10 to 30 feet high, decreasing in height northward. At Berea the stream flows in a narrow trench in sandstone and a fall and short gorge occur just north of the town, where the stream cuts through the sandstone into the shale below. From this point to the mouth of the river the valley is flat bottomed and steep walled, in a few places as much as a quarter of a mile wide, and has vertical walls of shale 100 feet or more in height. The West Branch has a similar fall and gorge at Olmsted Falls. Where the two branches come together at Olmsted, two prominent, isolated rock hills occur in the middle of the valley. They are quadrangular and bounded on all sides by precipitous shale bluffs. These are remnants of the shale promontory between the two branches of the river, which long ago came together below the hills, later cut across between them, forming the north hill, and later still came together as they now do.

At Kamms the stream crosses the old valley, which had been entirely filled with glacial drift, and here its present valley widens to three-quarters of a mile and its walls are of glacial drift and less steep than above. At the big bend at Rockport the valley reaches the east edge of the old filled valley, and the west wall of the present valley consists of drift and is in strong contrast with the shale cliff that forms the east wall.

The larger creeks of the quadrangles all have a fall over the Berea sandstone and a gorge below it. On many of those that flow into the Cuyahoga the falls are high and the gorge steep and long, as on Tinkers, Brandywine, and Chippewa Creeks. On those that flow to the lake—Euclid Creek and Doan Brook, for example—the gorge continues to the escarpment, beyond which the stream crosses the Erie Plain in a shallow valley.

A large part of the city of Cleveland is built on a nearly flat platform having a gentle northerly slope, on the surface of the Pleistocene deposits that fill the old Cuyahoga Valley. In this part of the city bedrock is far beneath the ground surface.

## DRAINAGE

*General character.*—The three quadrangles drain entirely into Lake Erie. The greater part of the drainage passes through northward-trending valleys of medium size, which are rather uniformly spaced across the region, one for every 10 to 15 miles or about one to each quadrangle. The Cuyahoga River is the stream of this type for the Cleveland quadrangle and the Rocky River for the Berea quadrangle. The Black and Chagrin Rivers are the corresponding streams for the quadrangles next west and east of the Cleveland district. The subsidiary drainage of the areas between the rivers flows into these rivers, except in that part nearest the lake, in which small streams flow directly into the lake. Euclid Creek and Doan Brook, both east of the Cuyahoga, are the largest of the minor tributaries to the lake. A notable tendency of the subsidiary drainage is to flow for considerable distances parallel to the shore of the lake instead of toward it. The low ridges that roughly parallel the lake shore—the lake ridges and the moraines—impose this course on the streams. The East Branch of Euclid Creek flows southwestward along the south face of the Euclid moraine. Butternut Ridge turns Big Creek out of its northerly course at North Linndale, sharply eastward to the Cuyahoga. A number of small brooks flow behind the lake ridges in the Berea quadrangle.

The streams of the plateau flow in all directions, but those that do not flow north become tributary to some stream that does flow north. Thus in the southern part of the Cleveland quadrangle Furnace Run flows southeast, but it reaches the Cuyahoga south of the limits of the quadrangle. The extreme upper part of the East Branch of the Rocky River flows southeast, in the reverse direction to a lower part of its own flow to the northwest. These various directions are controlled by the local surface slopes, which in turn are largely due to modification of the normal slopes by glacial deposits.

*Cuyahoga River and other streams.*—The Cuyahoga River is about 100 miles long. It rises in the highlands of Geauga County within 15 miles of the lake shore and flows 60 miles southward and southwestward away from the lake. It reaches the old preglacial valley, in which it flows northward to the lake, at a place 30 miles southeast of Cleveland. Its course is separable into three parts—the long upper, southwesterly course, which is in a shallow and uneven channel through glacial topography, with no well-marked valley, and in which the fall is 600 feet, or about 9 feet to the mile; a short middle course, where it falls 220 feet in a gorge 1½ miles long, cut back into the east wall of the old valley; and the lower, northward course in the old valley, the only portion within these quadrangles.

The Cuyahoga carries to the lake the entire drainage of the Cleveland quandrangle, except the extreme northeast and southwest corners, and also the Big Creek drainage of the eastern part of the Berea quadrangle. The stream is thoroughly graded, except for a few small rapids. It is very tortuous, its name, of Indian origin, meaning "crooked." Its actual length across the Cleveland quadrangle, following the channel, is more than 40 miles, or more than twice as great as the air-line distance along the valley. In this distance it drops 80 feet, so that the fall is less than 2 feet to the mile, which is much gentler than that of any other stream of the region.

The average discharge of the river at Independence is about 700 second-feet, from a drainage basin containing about 900 square miles, which is about 0.8 second-foot to the square mile. The flow is much the largest in March and least in midwinter and midsummer.

The chief tributaries to the Cuyahoga are Tinkers, Brandywine, and Mill Creeks from the east and Chippewa and Big Creeks and Furnace Run from the west. Tinkers Creek is the largest of these. It enters the quadrangle at the place where a moraine diverts it sharply westward from the old valley occupied by its upper part. In strong contrast to its broad upper valley, it occupies within the Cleveland quadrangle a narrow, steep-walled gorge, 100 feet deep, with a 30-foot fall over the Berea sandstone at the head of the gorge at Bedford. This part of its course is less than 7 miles long, and the drop is 310 feet, or 45 feet to the mile. Its upper course is longer and has a much gentler gradient of about 7 feet to the mile. Big Creek is about 14 miles long and drops 630 feet, an average grade of 45 feet to the mile. It is a shorter and smaller stream than Tinkers Creek and should normally have a steeper slope. Chippewa Creek is about 7 miles in length and has a drop of more than 500 feet within that distance, or more than 70 feet to the mile, with its falls over the Berea sandstone just below Brecksville. The fall of Brandywine Creek over the Berea sandstone at Brandywine, a straight plunge of 75 feet, is the highest fall within the quadrangles. Mill Creek has a similar profile.

The Rocky River is a much smaller stream than the Cuyahoga, though no measurements are known of its volume. The source of the East Branch is not more than 30 miles south of the lake, and, except the headward part, it flows directly toward the lake. With the East Branch it is about 35 miles long and has a gradient of about 18 feet to the mile. Across the Berea quadrangle the West Branch falls about 10 feet to the mile. This is two and one-half times the Cuyahoga gradient, and the discrepancy is due chiefly to the differences in the two valleys, which have already been described.

The Euclid quadrangle is drained by streams that flow directly into the lake, chiefly Euclid Creek, Doan Brook, Dugway Brook, and Ninemile Creek. These all rise well back from the escarpment, on the gentle shale slopes of the Appalachian Plateaus in Warrensville Township, and flow northward in very shallow, narrow valleys to the places where they fall over the Berea sandstone into narrow, rock-walled valleys about 100 feet deep that have been cut backward from the edge of the Appalachian Plateaus. From the escarpment at the edge of the plateau they flow northward in shallow trenches in the Erie Plain to the lake.

The Erie Plain is so narrow across most of the district that it has no drainage distinct from the plateau; a number of small streams head on the escarpment and flow directly across it to the lake. West of the Rocky River, where the plain broadens, the entire drainage of the plain consists of such streams, of which Cahoon and Porter Creeks are the largest. In this district the headwater parts of such creeks are much deflected by the lake ridges that cross their courses, as shown on the topographic map. Their valleys are shallow except near the lake, where they notch the shore cliffs, some to depths of 30 to 50 feet. The larger streams all flow across the plain in sharply cut, generally narrow valleys from 50 to 100 feet deep.

*Springs.*—The two great porous sandstones of the region, the Berea and Sharon, give rise to a host of copious springs along their lines of outcrop. Many streams head in the springs from the Sharon. Although there are springs of other origin also, these are so constant and abundant that they form a characteristic feature of the drainage.

## BEDROCK SURFACE

In the Appalachian Plateaus the altitude, relief, and larger topographic features are due chiefly to the form of the bedrock surface, and only the minor drainage lines are completely filled by the drift. In the Erie Plain, however, the preglacial valleys are all filled about to the level of the interstream tracts, and it is only by boring that their positions and courses are determined. On the part of the plain within the Cleveland district the coating of drift on the preglacial interstream areas probably averages not more than 15 feet in thickness, but in northwestern Ohio these tracts as well as the preglacial valleys are covered with thick deposits of drift.

The most prominent parts of the Appalachian Plateaus within the Cleveland area have the resistant Sharon conglomerate as the cap rock. The Berea sandstone forms the immediate border of the Appalachian Plateaus east of the Cuyahoga River but runs into the Erie Plain near the west side of the Cleveland quadrangle. It stands somewhat above the area to the north of the plateau as far west as Berea but is buried under drift in the western half of the Berea quadrangle. This sandstone causes cascades on most of the streams that cross it.

The rock floor of the preglacial valleys is much lower than the beds of the present streams and in places much lower than the bed of Lake Erie. The present streams are controlled by the surface of the lake, but the preglacial drainage lines were connected with a trunk stream in the Erie Basin whose valley was cut to a level far below the bed of the present lake.

Borings in Cleveland and along the Cuyahoga Valley have shown the presence of a remarkably deep channel, with a rock floor in places near sea level. The preglacial valley is practically followed by the present river from Akron down as far as Willow, but from Willow to the lake the present river has a course farther west than the preglacial course. The borings indicate that the deepest part of the preglacial valley runs nearly north from Willow, along or near East Fifty-fifth Street, to the shore of Lake Erie. In two places the rock is reported to be below sea level—one at the shore of Lake Erie west of Gordon Park and the other east of Independence, about 12 miles from the lake. The records of several borings that show remarkably thick drift and low altitude of the bedrock have been collected by Prof. J. E. Hyde, of Western Reserve University. These records indicate a lower altitude near the east side of the preglacial Cuyahoga opposite Independence than in the middle and western parts of the valley.

There are two borings opposite the mouth of the preglacial valley of Tinkers Creek, one of which shows a rock floor 20 feet below sea level and the other 4 feet above. Five borings within an area of about 40 acres about half a mile farther west, near the middle of the valley, strike rock at 45, 50, 130, 275, and 306 feet above sea level. The borings reaching bedrock at 45 and 50 feet are a little farther east than the others. Several borings west of the middle of the valley enter rock at levels between 300 and 400 feet above sea level. The deep excavation thus seems to be confined to the eastern half of the old valley and to a width of about half a mile. The east bluff, only half a mile north of the place where the rock floor is lowest, has rock up to 800 feet above sea level and a mile farther north up to 930 feet. The bluff is therefore remarkably steep for a preglacial valley formed by subaerial erosion.

A line of borings running from east to west across the city of Cleveland, reported by Upham,[1] shows a similar condition, as appears in the table below, slightly modified from the original.

*Wells along or near Euclid and Detroit Avenues*

| | Distance west of Garfield Monument | Depth of drift |
|---|---|---|
| | *Miles* | *Feet* |
| Between Garfield Monument and Wade Park | 0.8 | 0 |
| Amesbury Avenue (East Ninety-third Street) | 1.5 | 35 |
| Lincoln Avenue (East Eighty-fourth Street) | 1.9 | 125 |
| East Madison Avenue (East Seventy-ninth Street) | 2.1 | 346 |
| Giddings Avenue (East Seventy-first Street) | 2.4 | 440 |
| Wilson Avenue (East Fifty-fifth Street) | 3.0 | 325 |
| Case Avenue (East Fortieth Street) | 3.3 | 320 |
| Dodge Street (East Sixteenth Street) | 4.4 | 250 |
| Hollenden Hotel | 4.7 | 220 |
| Public Square | 5.0 | 205 |
| Cuyahoga bottom lands [a] | 5.5 | 110 |
| Division Street near waterworks [a] | 6.3 | 108 |
| Waverly Avenue | 6.9 | 104 |
| Lake Avenue and Detroit Street | 7.5 | 75 |
| Lake Avenue and Edgewater Park | 7.9 | 55 |
| Near Mueller Avenue | 8.4 | 40 |
| At west city boundary near Highland Avenue | 9.5 | 20 |

[a] These 2 wells are on ground nearly 100 feet lower than the others.

[1] Upham, Warren, Geol. Soc. America Bull., vol. 8, p. 9, 1897.

With the two exceptions noted the wells are all about 100 feet above Lake Erie, so the deepest one recorded in the list strikes rock at 340 feet below the level of the lake, or 233 feet above sea level. There is, however, only one boring, that at East Seventy-first Street, within a distance of nine-tenths of a mile in the deep part of the valley. There is thus abundant room for a deeper channel about as wide as the deep one near Independence. Upham reported a boring north of this line, on ground only 50 feet above Lake Erie, that failed to reach rock at 520 feet, thus showing the rock surface there to be less than 100 feet above sea level.

Mr. H. A. Dempsey, a driller of Cleveland, reports a well drilled for the White Co., just southwest of Gordon Park, which reached rock at about sea level, or nearly the same as the level of the lowest bedrock surface near Independence. He also reports a well several miles to the south, just north of Forest City Park, which reached rock at about 40 feet above sea level. He argues from data that he possesses that there is a deep channel in the floor of the Cuyahoga Valley, cut down to or slightly below sea level and running from a point at least 15 miles south of the lake; and that the channel is narrow, its width being about a quarter of a mile. The data strongly suggest such a channel.

The Cuyahoga Valley is cut out of very weak shales, and before the discovery of this inner and narrow deep channel Cushing was disposed to maintain that the valley had been deepened by glacial action. This inner channel, however, would seem to be fatal to this view, as it must have been cut by a stream, and glacial deepening would have obliterated it, although if it had become filled with sand prior to the glacial advance, its narrowness would have prevented vigorous ice action along it. A certain amount of glacial erosion in the valley is definitely suggested by the nearly vertical attitude of the valley walls here and there, as at the mouth of the preglacial valley of Tinkers Creek, already described, and even more prominently on the east wall of the valley opposite Boston Mills, where there seems to be a nearly vertical rock wall at least 700 feet high.

Borings along the Rocky River, although showing a channel cut about 200 feet below the level of Lake Erie, have not given evidence of excavation to a level corresponding to that on the Cuyahoga Valley. It is possible, however, that borings have not penetrated to bedrock in the deepest part of the preglacial Rocky River channel, for only a few borings have been made along its course. The valley of the preglacial Rocky River makes a gap more than a mile wide in the shale bluff where it enters Lake Erie, a short distance west of its present mouth, so that many borings are needed in order to test its depth fully.

The preglacial Rocky River is followed by the East Branch across Strongsville Township, but thence the preglacial channel runs northward through Middleburg Township, passing east of Berea and embracing the headwater part of Abram Creek. It crosses to the west side of the present stream directly west of Kamms and continues a short distance west of the river from that point to the lake. The gap in the shale bluff west of the mouth of the present stream was interpreted by Newberry as marking the channel of the preglacial Rocky River, but the course of the channel was first traced by Dr. D. T. Gould, of Berea, several years later.

### CULTURE

These three quadrangles are situated in one of the most densely populated regions of North America. A large and rapidly growing city contains the greater part of the population; the city is closely adjoined by suburban towns and villages that are practically parts of it and one by one become incorporated with it; and the villages steadily expand into the surrounding rural territory. The rural areas also are evenly and densely populated. The exact population of the quadrangles can not be given, because they do not contain all of Cuyahoga County and do contain parts of Medina, Summit, and Lorain Counties. But as the part of Cuyahoga County that is not included in these quadrangles is roughly equivalent in area to the included parts of these other counties, as no large village is situated in either, and as the rural population is about equally dense in all, it seems reasonable to assume that the population of the quadrangles is the same as that of Cuyahoga County. This was in 1910, 637,425, or about 1,275 to the square mile; in 1920, 943,495, or 2,038 to the square mile; in 1930, 1,201,455, or 2,595 to the square mile.

The city of Cleveland in 1930 had a population of 900,429. Several immediately adjacent villages and towns are so closely grown to Cleveland that the community lines are obscure, although the civil distinctions remain. Bratenahl, East Cleveland, Euclid, South Euclid, Cleveland Heights, Shaker Heights, Garfield Heights, Newburg Heights, Lakewood, and Rocky River had in 1930 a population of 222,735. The Cleveland community, including these villages, together with thickly settled parts of adjacent townships, therefore probably has a total population of about 1,150,000.

The rural population is essentially agricultural. The Erie Plain is largely devoted to raising fruit, especially grapes. The whole district is under cultivation except a few excessively steep slopes, a few small marshy tracts, and parts of the high-level Pottsville (Sharon) conglomerate outliers. Owing to the nearness of the large city, truck gardening is extensively carried on. Especially well adapted to this purpose are the sandy surface of the Cleveland moraine in Brooklyn Township, the filled old valley of Rocky River, and the black-soil areas—formerly marsh accumulations—just south of the old lake beaches in the Berea quadrangle.

On the plateau wheat, corn, oats, and hay are the principal crops and some fruit is raised. Little forest remains in these quadrangles except in the narrow stream valleys and on the Sharon summits of the plateau. This forest consists chiefly of hardwoods, and there are many groves of sugar maple that supply a large run of sap in the early spring.

Cleveland is a large manufacturing center and has distribution both by lake and by rail. It is near an abundant supply of excellent coal and receives annually a huge tonnage of iron ore. A large proportion of each is used here, and the rest is transshipped. Manufacturing is far more diversified than in many other industrial centers. The city serves also as a distributing point for an extensive surrounding area. The quarry industry, of which both Berea and Euclid are or have been local centers, is large.

Two trunk-line railroads that follow the Erie Plain across Ohio, the New York Central and the New York, Chicago & St. Louis, pass through the quadrangles. Branch lines of the Pennsylvania, Baltimore & Ohio, and Erie Railroads run into Cleveland from the main lines of these systems, which cross the plateau on the south. The lines of the Big Four Route begin at Cleveland and run west and southwest, and the Wheeling & Lake Erie has a terminal here. The Belt Line Railroad encircles the city and connects all these railroads. Seven electric railroads radiate from the city, along the lake both east and west and to the southeast, south, and southwest, of which three have recently been considerably restricted in the length of their lines in operation.

Passenger steamers to Buffalo and to Detroit leave Cleveland daily in the navigation season. The through boats from Buffalo to the upper lakes all dock at the city. Lines also run to Sandusky and the islands and across the lake to Port Stanley. Freight steamers in great numbers ply the lake, loaded for the most part with iron ore, coal, or grain. This traffic is closed in winter.

The Ohio Canal, which formerly extended from Lake Erie to the Ohio River, passes up the Cuyahoga Valley from Cleveland. No use is made of it at present, except as a source of water supply by certain industries under lease from the State.

All parts of the quadrangles are reached by public roads, many of which are graveled, others are ordinary dirt roads, and some are of clay. Over the clay roads traffic is very difficult in wet weather. Practically all the chief highways are paved with brick, concrete, or asphalt, and the paving is constantly being extended.

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The chief obstacles to railway and highway construction are the deep Cuyahoga and Rocky River Valleys and the escarpment. Through east-west traffic has the grades of the valley walls to overcome; that to the south must climb from the level of the plain to that of the plateau. The valleys must be crossed by long and costly high-level bridges and viaducts, or else by steep grades. The New York Central Railroad crosses the Cuyahoga River at a low level (about 580 feet) near its mouth, and then swings far south to Berea, which is 200 feet higher, so as to cross the two branches of the Rocky River above the falls and gorge. Westbound trains from Cleveland therefore have a heavy grade to overcome. Eastward the rise is more gradual. The New York, Chicago & St. Louis Railroad crosses the Cuyahoga Valley farther south by a long, high trestle, and the Belt Line crosses by a still higher one. Most of the roads running southward have steep grades across the quadrangles. The Baltimore & Ohio Railroad runs up the Cuyahoga Valley with a lower grade than that of any other of these roads, but this grade is balanced in part by an exceedingly heavy grade where the road leaves the valley at Akron. The other railroads utilize small branch valleys. The Big Four goes up Walworth Run, the Erie up one branch of Kingsbury Run, the Wheeling & Lake Erie up Morgan Run, and the Pennsylvania follows in part the shallow valleys of Mill and Brandywine Creeks. In its 20-mile course across the Euclid and Cleveland quadrangles the Pennsylvania roadbed rises 420 feet, an average of 21 feet to the mile; this is a fair sample of the grades that must be overcome in passing from the Erie Plain to the Appalachian Plateaus, unless heavy construction is resorted to. The more recent Pittsburgh & Lake Erie Railroad, a unit of the New York Central system (not shown on the topographic map but following the east wall of the Cuyahoga Valley), by a series of great fills and bridges across the tributary valleys, accomplishes the ascent by a grade of about 15 feet to the mile over many miles in length.

## STRATIGRAPHY

### GENERAL FEATURES

By H. P. Cushing

The exposed rocks of the three quadrangles are wholly of sedimentary origin and range in age from late Devonian to Pleistocene. They fall into two general classes—indurated stratified rocks of late Devonian and early Carboniferous age and unconsolidated surficial deposits of Pleistocene age. The Pleistocene deposits form a blanket of relatively slight thickness over the surface of nearly the whole district. The indurated rocks everywhere underlie them and crop out in the beds and gorges of streams, in the escarpments, and in a few other places, and they have been exposed in numerous quarries and other excavations. (See pl. 20.)

The total thickness of Paleozoic strata exposed in the quadrangles is about 750 feet. The beds consist of shale, sandstone, and conglomerate of late Devonian, early Mississippian, and early Pennsylvanian age. There is as yet a lack of agreement among geologists as to the horizon where the line between the Devonian and Mississippian rocks should be drawn in this region. The Chagrin shale is of late upper Devonian age, belonging chiefly if not wholly to the Chemung epoch; the Cleveland and Bedford shales are classed by some geologists as uppermost Devonian and by others as lowest Mississippian; and the Berea sandstone and overlying Orangeville and Meadville shales are classed by all as Mississippian. Rocks of late Mississippian age are completely lacking in these quadrangles, so that the Sharon conglomerate, of early Pennsylvanian age, the youngest Paleozoic formation of the quadrangles, rests unconformably upon the eroded surface of the Mississippian beds.

The rocks that are exposed are underlain by a large thickness of Devonian, Silurian, and Ordovician formations, and presumably of Cambrian also, resting on a floor of pre-Cambrian crystalline rocks. Many of these buried strata crop out in the western half of the State, so that their general character is known. Around Cleveland they have been identified in a general way by means of borings, some of which have penetrated more than 3,000 feet below the level of the lake. Their general character, sequence, and approximate thickness are shown graphically in Figure 3.

The superficial deposits comprise Pleistocene glacial and lacustrine deposits and Recent alluvium. They were formed under widely different conditions and occur in different parts of the area, and although their general order of superposition has been ascertained they do not form a continuous sequence of deposits and can not well be represented in a columnar section. They will be described in their appropriate place.

## ROCKS NOT EXPOSED

By H. P. Cushing

*General features.*—Below ground the drill passes first through several hundred feet of shale and continues through a great thickness of limestone with less amounts of shale, gypsum, and salt, called the Big lime by the driller. Below this material a varying series of shale and limestone with a few thin bands of sandstone is passed through. This series also is very thick, no boring yet having reached its base. The upper shale and the Big lime are the buried parts of formations of Devonian and Silurian age that can be studied in outcrop along the Erie Plain west of Cleveland and can be recognized in a general way in the well records. The rocks below the Big lime are of early Silurian and Ordovician age, but surface outcrops of these are more remote, and accurate comparisons are impossible.

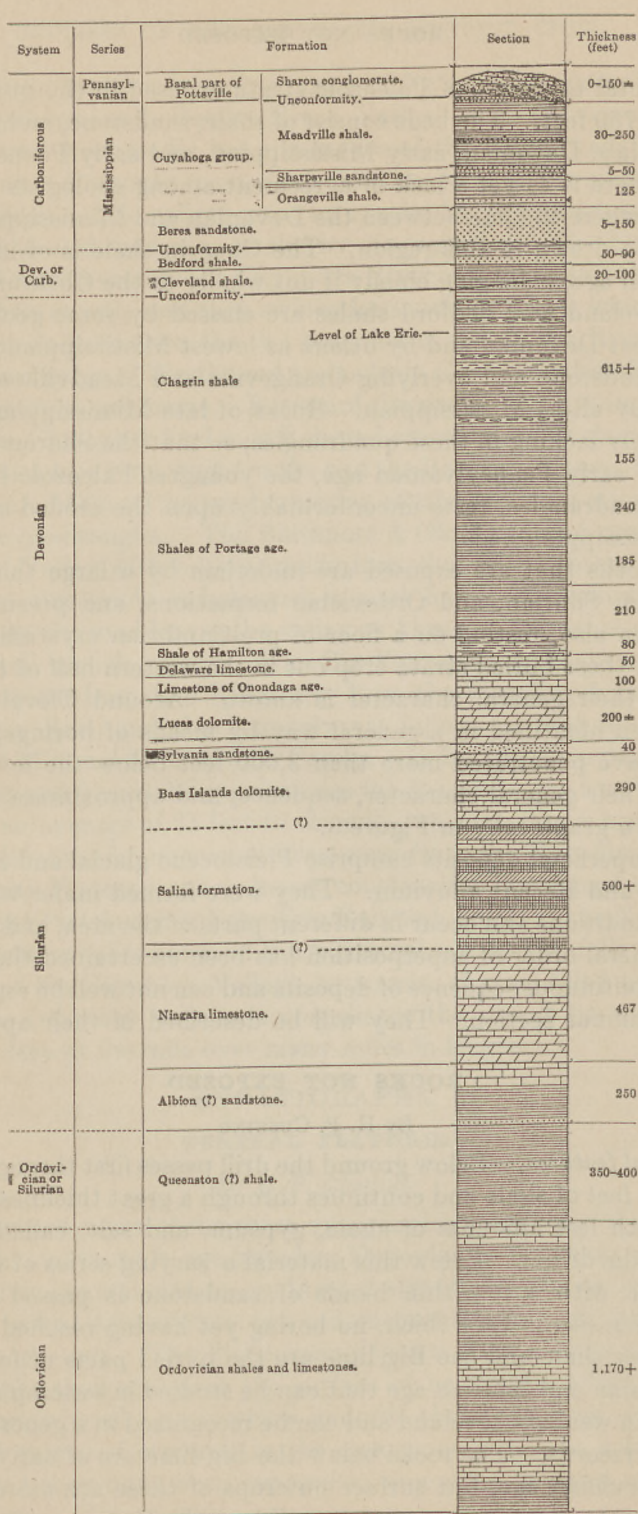


FIGURE 3.—Generalized columnar section of the exposed rocks of the Cleveland, Berea, and Euclid quadrangles and of the rocks that have been penetrated in deep wells at Cleveland, Berea, and Lorain

*Ordovician and early Silurian rocks.*—A deep well drilled in 1910 at Lorain, 8 miles west of the Berea quadrangle, reached a depth of 3,720 feet, 1,700 feet below the base of the Big lime, and one at Berea, drilled three years earlier, stopped at 3,200 feet and passed through 734 feet of strata beneath the Big lime.

*Logs of deep wells at Lorain and Berea*

| Lorain | | | Berea | | |
|---|---|---|---|---|---|
| | Thickness (feet) | Depth (feet) | | Thickness (feet) | Depth (feet) |
| Shale | 750 | 750 | Shale | 1,075 | 1,075 |
| Big lime | 1,270 | 2,020 | Big lime | 1,391 | 2,466 |
| Shale | 25 | 2,045 | Blue shale | 239 | 2,705 |
| Sandstone | 30 | 2,075 | Red shale | 345 | 3,050 |
| Shell | 33 | 2,108 | Dark shale | 150 | 3,200 |
| Sandstone | 2 | 2,110 | | | |
| Slate | 23 | 2,133 | | | |
| Red shale | 17 | 2,150 | | | |
| Sand (?) | 65 | 2,215 | | | |
| Red shale | 247 | 2,462 | | | |
| Red sand | 58 | 2,520 | | | |
| White slate | 10 | 2,530 | | | |
| Red shale | 20 | 2,550 | | | |
| Sandy limestone | 30 | 2,580 | | | |
| Slate | 15 | 2,595 | | | |
| Sandy limestone | 10 | 2,605 | | | |
| White shale | 545 | 3,150 | | | |
| Brown "sand" | 167 | 3,317 | | | |
| Slate | 233 | 3,550 | | | |
| Sandy limestone | 50 | 3,600 | | | |
| Slate | 30 | 3,630 | | | |
| Sandy limestone | 90 | 3,720 | | | |

The shale and limestone below the red beds in these wells are no doubt of Ordovician age and in the Lorain well very probably reach down into the early Ordovician (Beekmantown). The red beds themselves, 350 to 400 feet thick, probably represent the Queenston shale, whose nearest outcrops are in the Niagara Gorge and the peninsula of Ontario. They consist chiefly of very soft, very red shales, with interbedded sandstones that differ much from place to place. These sandstones are usually gray or greenish, and the red sand reported in the Lorain record may have been discolored from the shale above during drilling. Above the red shales come calcareous shales and thin limestones to the base of the Big lime. Locally a sandstone, which in western Cleveland and Lakewood is charged with natural gas, occurs in them near the base. Some of these beds have a reddish tinge, though by no means so red as the Queenston (?) shale. In Ohio they have commonly been referred to the Clinton but are probably the representatives of the Albion sandstone. The drillers of the gas wells in Cleveland have paid particular attention to recording the beds at this horizon, and one of their well records will give a better idea of them than the records already quoted.

*Record of gas well of Upson Nut Co., Cleveland*

| | Thickness (feet) | Depth (feet) | | Thickness (feet) | Depth (feet) |
|---|---|---|---|---|---|
| Sand and gravel | 84 | 84 | Newburg sand | 15 | 2,405 |
| Clay and loam | 101 | 185 | Limestone, hard | 230 | 2,635 |
| Shale | 985 | 1,170 | Slate and shell | 45 | 2,680 |
| Limestone | 105 | 1,275 | Stray sand | 20 | 2,700 |
| Limestone, with water | 305 | 1,580 | Slate | 8 | 2,708 |
| Limestone, dry | 245 | 1,825 | Pink Clinton sand | 20 | 2,728 |
| Salt and anhydrite | 105 | 1,930 | Slate | 12 | 2,740 |
| Limestone | 460 | 2,390 | Slate and shell | 38 | 2,778 |

The pink sand near the bottom of the section is the sand referred to. Its thickness in few places in the Cleveland district exceeds 20 feet, and in many wells it is absent.

Across northeastern Ohio the Big lime is sharply separated into two distinct portions by the occurrence of an intermediate series of beds that contain rock salt and gypsum. The limestone below the salt beds is chiefly of Niagaran age, has a thickness of about 500 feet, and in the upper half at least consists largely or wholly of dolomite. Midway in this limestone is another "sand," which is known to the drillers as the Newburg sand. It lies about 300 feet higher in the section than the so-called Clinton sand and ranges in thickness from 15 or 20 feet down to the vanishing point. It is not a true sand but a granular, porous dolomite. Locally it contains considerable gas and a small quantity of oil.

*Late Silurian* (*Cayugan*) *rocks*.—Beds of Salina age, consisting of alternations of rock salt, anhydrite (or gypsum), dolomite, and shale, are reported in practically all the drilled wells in the Cleveland district that reach the necessary depth. The formation has a thickness of at least 500 feet, and probably some of the limestone both above and below also belongs with it. There are several beds of fairly pure rock salt, in many places having an aggregate thickness of 150 feet or more. In addition the interbedded limestones are more or less cavernous, and many of the cavities are filled with salt. The amount of salt, however, varies much from place to place and very irregularly. The well of the Cleveland Rolling Mill Co., drilled in 1885, was the first to penetrate the salt deposit, and its record gives as good an idea of the thickness and arrangement of the beds as any other. The part of the record concerned is as follows:

*Partial log of well of Cleveland Rolling Mill Co.*

| | Thickness (feet) | Depth (feet) | | Thickness (feet) | Depth (feet) |
|---|---|---|---|---|---|
| Limestone | 1,990 | 1,990 | Shale | 18 | 2,378 |
| Rock salt and shale | 164 | 2,154 | Limestone | 22 | 2,400 |
| Anhydrite | 15 | 2,169 | Rock salt | 20 | 2,420 |
| Limestone | 81 | 2,250 | Anhydrite | 10 | 2,430 |
| Rock salt | 50 | 2,300 | Limestone | 40 | 2,470 |
| Anhydrite | 40 | 2,340 | Rock salt | 5 | 2,475 |
| "Sand" | 20 | 2,360 | Anhydrite | 8 | 2,483 |

Orton reports that the 164-foot unit consisted of alternate beds of salt, anhydrite, limestone, and shale, the details of which were not recorded by the driller. A well of the Union Salt Co., in Cleveland, gives four alternations of salt and limestone in the upper 176 feet of the Salina, the salt aggregating 131 feet.[2]

In contrast to the 500-foot thickness of beds containing salt and anhydrite in the rolling-mill well, only 105 feet is reported from the Upson well. Some wells farther west, as at Berea and Lorain, report none, and no salt is reported in any well west of Elyria. Furthermore, the thickness of the Big lime in that region is much the same as it is in the Cleveland district, if the thickness of the Salina is deducted. The Big lime is 1,100 feet thick at Sandusky and from 1,500 to 1,700 feet thick at Cleveland, where from 400 to possibly 600 feet of the thickness belongs to the Salina. This suggests the probability that the Salina rocks wedge out at Elyria and are absent west of that point. (See pp. 83, 86.)

The overlying Silurian beds are assigned to the Bass Islands dolomite, of Cayugan age. The carefully kept record of the rolling-mill well indicates a thickness between 250 and 300 feet for this dolomite, which lithologically resembles the Devonian Lucas dolomite.

*Devonian limestones.*—The basal Devonian formation in this area is the Sylvania sandstone, about 40 feet thick, which is overlain by the Lucas dolomite and younger limestones of Devonian age. In the rolling-mill well the Lucas is about 200 feet thick. In most of the wells the driller does not differentiate the Sylvania sandstone and includes the Bass Islands, Sylvania, and Lucas in the general mass of the Big lime. The Lucas and Bass Islands dolomites consist chiefly of compact magnesian limestone, generally brown but with some light-gray or dark-blue beds, of which the dark-blue beds are more calcareous than the rest. Many of the beds consist of angular breccias, have sun-cracked surfaces, and may be distinctly laminated. The freshly broken rock smells of petroleum. Many layers contain thin streaks of carbonaceous matter parallel with the bedding planes. The rocks are mostly thin and rather evenly bedded, though some are in massive layers. The outcrops on the Bass Islands and at Put in Bay are well known to most residents of Cleveland.

The Sylvania sandstone in its outcrop is a pure porous quartz sand. Underground it becomes less porous and has a calcareous cement. In the area in which it crops out it is much used as a glass sand.

The upper part of the Big lime consists of the limestone of Onondaga age and the Delaware limestone, both belonging to the Middle Devonian, the Delaware limestone being chiefly if not wholly of Hamilton age.

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[2] Ohio Geol. Survey Bull. 8, p. 35, 1906.

The limestone of Onondaga age in northern Ohio has a thickness of 60 to 100 feet. Its nearest outcrops to Cleveland are at Sandusky and Marblehead and on Kelleys Island. This limestone is chiefly gray to brown, but its upper part is blue. The lower half of the formation is highly magnesian; the upper half much less so. Massive beds, as much as 10 feet thick, alternate with much thinner beds. In some layers there are nodules of light-colored chert, and many contain an abundance of beautifully preserved fossils.

At Sandusky the overlying Delaware limestone is also exposed, and its thickness here and elsewhere in northern Ohio is about 60 feet. It is chiefly a thin-bedded blue rock with nodules of light-colored chert in many of the beds. It is less magnesian and not so fossiliferous as the beds of Onondaga age.

*Devonian shales.*—The most carefully kept and most detailed record of the shale series above the Big lime is supplied by a well near the corner of Euclid Avenue and East Fortieth Street in Cleveland.[3] Its record follows:

*Log of well near Euclid Avenue and East Fortieth Street, Cleveland*

| | Thickness (feet) | Depth (feet) | | Thickness (feet) | Depth (feet) |
|---|---|---|---|---|---|
| Drift beds | 300 | 300 | Black shale (with *Sporangites*) | 15 | 655 |
| Blue shale | 10 | 310 | Gray shale | 60 | 715 |
| Black shale | 40 | 350 | Black shale (many *Sporangites*) | 15 | 730 |
| Dark shale | 25 | 375 | Gray shale | 65 | 795 |
| Dark shale (lighter than overlying bed) | 40 | 415 | Black shale | 55 | 850 |
| Gray shale | 30 | 445 | Gray shale, calcareous | 80 | 930 |
| Black shale | 10 | 455 | Limestone | 60 | 990 |
| Gray shale | 185 | 640 | | | |

The 80 feet of calcareous gray shale near the bottom of the section no doubt is of Hamilton age and overlies the Delaware limestone in the Sandusky region. The overlying shales are of Portage age, and the alternations of black shale and gray or blue shale, with a thick band of gray shale midway, are characteristic of these shales throughout the region. These alternating black and gray shales, with a thickness of more than 600 feet, were called Huron shale by Newberry, who correlated them with the shales along the Huron River, the type locality. Newberry's view is still held by many geologists. Others, of whom the writer is one, believe that the two shales have nothing to do with each other, that these underground shales of the Cleveland section pinch out before the Huron River is reached, and that the true Huron shale is a higher formation and is wholly unrepresented in the section at Cleveland. The lower part of the Chagrin shale is also not exposed in the Cleveland region.

[3] Ohio Geol. Survey Rept., vol. 6, p. 429, 1888.

## ROCKS EXPOSED

The sequence, thickness, and general character of the late Devonian and early Carboniferous rocks that are exposed in the three quadrangles are shown graphically in the columnar section (fig. 3), and their detailed description follows.

## DEVONIAN SYSTEM

By H. P. Cushing

### CHAGRIN SHALE

*Definition.*—The Chagrin shale was named from the Chagrin River, along which between Willoughby and Gates Mill are many cliffs that excellently expose much of the upper part of the formation. It consists of very soft and pure greenish-gray or bluish-gray clay shale, with a few thin bands of flagstone and more numerous bands of flattened, hard reddish concretions. The drill shows it to have a thickness of about 500 feet at Cleveland, but only the uppermost 175 feet is exposed, and the remainder lies beneath the level of the lake.

The formation was originally called the "Erie shale," but the name was in 1903 changed to Chagrin, because Erie was preoccupied.

*Distribution and occurrence.*—In the Euclid and Cleveland quadrangles the Chagrin shale occupies the entire surface of the Erie Plain between the escarpment and the lake, also the lower part of the slope of the escarpment. It extends up the Cuyahoga Valley to and beyond the south margin of the Cleveland quadrangle, and up the valleys of the smaller streams, notably Euclid, Tinkers, and Big Creeks. West of the Cuyahoga the westward dip carries more and more of the formation below the level of the lake, and much of the Erie Plain is covered by the overlying Cleveland shale. Along the Rocky River only 80 feet of the formation remains above the lake surface, and at the west edge of the Berea quadrangle its top passes beneath the lake. Between the Cuyahoga and Rocky Rivers it is the surface rock of a strip of the Erie plain about 1 mile broad. It runs up the Rocky River Valley for about 4 miles, but west of this river it is for the most part confined to the cliffs along the lake. The chief exposures are in the stream beds and banks and in the lake cliffs. Nearly everywhere else it is covered by drift, in some places very thinly, in others very deeply.

*Character.*—The formation consists characteristically of blue-gray clay shale. In the unweathered material shaly cleavage is not prominent, and the rock is obtained from pits and excavations in large solid masses. Fragments of the rock are readily crushed to an impalpable powder beneath a hammer or pestle. On exposure it weathers very quickly to a soft sticky clay instead of crumbling to platy fragments. As exposed in steep cliffs along the streams it is so soft yet so tenacious that it becomes gullied by the rains from top to bottom, as may be seen on Euclid Creek. (See pl. 1.) Stones thrown against such a cliff when it is damp often adhere or even deeply embed themselves instead of rebounding and falling to the base.

Thin layers of flattened concretions 1 inch or less in thickness and from 3 to 8 inches in diameter occur in the formation. The concretions are blue within and are exceedingly tough and hard, containing a considerable percentage of lime and iron carbonates. On exposure to the weather they stain reddish by the oxidation of the iron to limonite.

Layers of shaly sandstone, generally thin but reaching in places a thickness of 6 inches, are of common occurrence in the formation but are very irregularly distributed. As a rule they contain many flakes of silvery mica, and in places they are finely laminated. They commonly contain marcasite, and marcasite concretions are scattered throughout the formation.

*Variation.*—South and east of Cleveland the extreme upper part of the formation is of somewhat different character. Sandy greenish-gray shale of slightly calcareous nature is interbedded with the soft blue shale, and locally thin bands of gray impure limestone are also found. Calcareous concretions appear in the soft shales in spotty fashion instead of being in continuous bands, and they are much less flattened than the concretions in the bands. These upper beds contain fossils more or less abundantly and in that respect also differ from the main mass of the formation.

West of Cleveland the upper part of the formation becomes much more sandy. The sections along Big Creek and the Rocky River show a much greater proportion of sandy beds in the uppermost 50 feet of the formation than is found at or east of Cleveland. These beds are thinly laminated fine-grained gray micaceous sandstones, many of them containing marcasite, which are quite like the less common beds elsewhere. Here they are more numerous and thicker. a few beds reaching a thickness of 6 inches. In the most western localities, west of the Rocky River along the lake shore, thin beds of black shale are interbedded with the blue shale and sandstone in the upper part of the formation. These beds are softer and less black than the typical black shale of the district but are quite distinct from the blue-gray shale.

*Fossils.*—Fossils are practically absent from the Chagrin shale in the Cleveland district, except in the uppermost few feet of it south and east of the city. Elsewhere none are found except obscure markings on the surfaces of some of the sandy beds which suggest fucoids and worm trails but whose real nature is wholly problematic. The upper beds carry a fauna consisting chiefly of brachiopods, in which a few forms are very abundant and a considerable number of others are very scarce. This fauna has never been exhaustively collected and studied, but a partial list is here given:

Chonetes setiger.
Spirifer disjunctus.
Dalmanella tioga.
Camarotoechia contracta.
Camarotoechia orbicularis.
Camarotoechia sp.
Leiorhynchus mesicostale.
Sphenotus clavulus?
Grammysia communis?
Gomphoceras sp.
Sphenotus contractus.
Lingula sp.
Reticularia praematura.
Productella lachrymosa.
Productella hirsuta.
Athyris polita?
Cyrtia alta.
Streptorhynchus chemungensis.
Ambocoelia umbonata.
Edmondia obliqua?
Euomphalus hecale.
Spathiocaris chemungensis.
Schizodus cf. S. chemungensis.
Leptodesma sp.

The most favorable localities for collecting Chagrin fossils in the district are on Tinkers Creek below Bedford and on Chippewa Creek east of Brecksville. They may also be found in Brandywine Creek but are very rare on Big Creek. They are not known to occur in the Euclid Creek or Doan Brook sections or anywhere else in or west of Cleveland.

*Age and correlation.*—The fauna found in the Chagrin shale permits its fairly definite correlation with the Upper Devonian Chemung formation of New York. The faunas are not identical in all respects, however, and the Chagrin fauna is closest to the fauna of the extreme upper Chemung, as it appears in western New York and Pennsylvania.

The variations in the formation across the district, which have been already described, are but the local phases of a variation which the formation exhibits across all of northeastern Ohio. East of Cleveland the formation steadily thickens, and it is at least 700 feet thicker at the Pennsylvania State line than it is at Cleveland. In the eastern part of the State the fossils range down through a thickness of several hundred feet instead of being limited to the top layer, as at Cleveland. West of Cleveland the formation passes beneath the lake level, and what becomes of it is uncertain, though unquestionably its thinning continues. Some geologists hold that it pinches out entirely before the Huron River is reached; others believe that it changes in character westward, passing laterally into a black shale.

## DEVONIAN OR CARBONIFEROUS ROCKS

### CLEVELAND SHALE

*Definition.*—The type locality of the Cleveland shale is at Cleveland and more particularly the Doan Brook section, in the eastern part of the city. It has there a thickness of about 50 feet and is excellently exposed in two cliffs along the brook, in a cut along North Park Boulevard, and along the Cedar Road hill. Its contact with the underlying Chagrin shale is well shown along the brook, and the contact with the overlying Bedford shale in the boulevard cut. It consists chiefly of very black fissile shale, most of which weathers with considerable rapidity to loose masses of thin, slaty fragments that rapidly stain brown. Some layers are thicker and weather much less rapidly. Sharp difference of opinion prevails as to the precise age of this formation; it is classed in the Devonian by many geologists, whereas others regard it as belonging to the Carboniferous.

*Distribution and occurrence.*—At and east of Cleveland most of the outcrops of Cleveland shale are on the front of the escarpment or on the steep banks of streams, so that they occupy only a very narrow strip of territory. At and beyond Euclid the formation extends to the top of the first rise of the escarpment and has a greater breadth of outcrop. West of the Cuyahoga it lies wholly north of the escarpment and occupies a broad zone on the surface of the Erie Plain—a zone that steadily broadens toward the west and is from 3 to 5 miles wide across the Berea quadrangle, because the width of the Erie Plain increases west of the Cuyahoga. Farther west, owing to the westerly dip, the formation is largely confined to the lake cliffs and at Avon Point its base is practically down to lake level. It is exposed continuously in the lake cliffs in Avon Township. East of Cleveland it crops out on the escarpment slope and at many places in road and railroad cuts. The most impressive display is that along the Rocky River between Berea and Kamms; for a distance of 4 miles along the valley there are numerous vertical cliffs that are composed of Cleveland shale from top to bottom.

*Character.*—The Cleveland shale consists of a lower and an upper division, which exhibit considerable lithologic contrast and differ greatly in distribution. The upper division consists entirely of black shale, whereas blue shale and thin hard sandstones alternate with the black shale in the lower division, which is herein called the Olmsted shale member. East and south of Euclid and Cleveland only the upper division occurs. In the Euclid Creek and Doan Brook sections and west of Cleveland the lower or Olmsted shale member is present, and it increases rapidly in thickness westward until it greatly exceeds the thin upper division. The whole formation has a thickness of about 100 feet on the west margin of the Berea quadrangle, about 75 feet on the Rocky River, 70 feet on Big Creek, 55 feet on Doan Brook and Euclid Creek, and 18 feet on Tinkers Creek.

The upper division of the Cleveland shale consists of black, mostly very fissile shale and has a thickness of 20 to 40 feet. It is present everywhere within the area mapped except where it has been removed by erosion. It has a deep, dull-black color when freshly broken and moist; when dry it is gray-black. It contains many tiny scales of white mica, most of them too minute to be seen except with the aid of a lens. Otherwise the rock seems to be constituted of uniform black mud. There is much marcasite (iron sulphide) in the rock, chiefly as concretions. On weathering the iron oxidizes, staining the shale brown and forming sulphates, and the rock breaks down into brown slaty fragments, the surfaces of many of which are mottled with thin crystals of gypsum or pickeringite. Most of the shale has a very pronounced cleavage and on weathering splits readily into thin, even sheets. Some beds are much more massive, and the rock splits irregularly and with difficulty and weathers into concentric shells that break up into flat flakes. These beds are found in the upper part of the formation or alternate with the more slaty beds.

The lower division or Olmsted shale member consists chiefly of black shale but contains also beds of blue shale and of thin gray sandstone and here and there a thin calcareous bed with the peculiar structure known as cone in cone. Much of the black shale in the Olmsted member is softer and less black and slaty than the black shale of the upper division, though beds of both types alternate. The blue shale is blue-gray, soft, and fissile and weathers into thin leaves, in this respect differing materially from the soft shale of the Chagrin, which weathers down to masses of sticky clay. The Olmsted member is absent from the Cuyahoga Valley.

The sandstones of the Cleveland shale are thin, laminated micaceous light-gray flags, much like those in the Chagrin but usually smoother and less apt to show the rough markings found on the under surfaces of many of the Chagrin flags. They are mostly confined to the lower part of the Olmsted member. In the upper part very thin layers of white papery flags occur in places.

The cone-in-cone beds consist of thin light-gray limestone, from 1 to 3 inches thick, are of lenticular form, and pinch out at no great distance. They are common in the western sections of the Olmsted member of the Cleveland but are unknown east of the Rocky River. They are not found in the upper division of the formation so far as known.

*Fossils.*—Throughout most of the Cleveland shale fossil remains or traces of any kind are very scarce. But here and there a bed holds them in abundance, and all beds contain a few. The fossils are of few kinds, consisting of remains of fishes, fragments of plants, shells of a few species of brachiopods, chiefly of the inarticulate group, shells of uncertain nature but probably belonging to a crustacean, and tiny conodonts. The more common brachiopods are *Orbiculoidea herzeri* and *Lingula melie*, but they are of very erratic distribution. Within the area shown on the map the writer has found them only on Euclid Creek and in the sections in southern Cleveland (Mill Creek, Belt Line cut, Cleveland & Youngstown cut). Here they are found only in the extreme upper layer of the black shale, which is only a few inches thick and which presents features suggesting that it consists of reworked black mud and really belongs with the overlying Bedford shale. It also contains rare specimens of other brachiopods, which suggest the Bedford forms.

Supposed crustaceans are found in both divisions. In the upper division the form is large, *Spathiocaris williamsi;* in the Olmsted member the much smaller species *S. cushingi* is found. This is the most abundant fossil in the Olmsted shale, being especially common in the lower layers of black shale, and it seems an excellent horizon marker. As lower and lower beds of this shale appear in passing westward, this fossil invariably follows them down, and it has been found in every section of the formation in the Berea quadrangle.

Fragments of plants occur rather abundantly as fossils, especially in the Olmsted member. In some layers *Sporangites* are very numerous

The most notable fossils of the Cleveland shale are the fish remains. Single tiny scales of ganoids are the most common fossils in the formation; teeth and spines of sharks are occasionally found; and in a few localities the careful and laborious search of local observers has resulted in considerable collections of the bony plates and jaws of large, armored fishes of ancient types and of other classes of fishes as well. From the valleys of the Rocky River and Big Creek and from the shales in the eastern part of the city of Cleveland such collections have been made. The material has come from both the upper and lower divisions of the formation but chiefly from the lower (Olmsted shale member). A list of the fishes found here follows:

Cladodus claypolei.
Cladodus rivi-petrosi.
Monocladus clarki.
Monocladus pinnatus.
Cladoselache clarki.
Cladoselache fyleri.
Cladoselache kepleri.
Cladoselache sinuatus.
Hoplonchus parvulus.
Ctenacanthus clarki.
Coccosteus cuyahogae.
Dinichthys clarki.
Dinichthys curtus.
Dinichthys gouldi.
Dinichthys gracilis.
Dinichthys prentis-clarki.
Brontichthys clarki.
Titanichthys attenuatus.
Titanichthys brevis.
Titanichthys clarki.
Trachosteus clarki.
Ctenodus wagneri.
Actinophorus clarki.

West of the district mapped such fish remains have been found at several points in Lorain County together with some species not in the above list because they have not yet been seen in the Cleveland district.

*Unconformity between the Cleveland and Chagrin shales.*—In all sections from the Rocky River eastward the contact between the Chagrin and Cleveland shales is very clear cut and appears very even. (See pl. 2, *A.*) Yet careful study shows that it is not really even but that the Cleveland rests on different beds of the Chagrin shale at different outcrops. The Cleveland has a basal bed heavily charged with marcasite, and this bed differs in thickness from place to place, owing to trifling irregularities in the surface on which it was deposited. The upper bed of the Chagrin shale is overlain in many places by a thin streak of soft, clayey material, which exhibits a weathered character even where the shale above and below it is perfectly sound and fresh, suggesting that it was weathered before the Cleveland shale was deposited upon it, and that a time of emergence separated the two epochs of shale deposition. There is certainly a break between the two formations, and to the writer it appears to be much the most widespread and significant break in the series and to mark the line between the Devonian and Carboniferous systems. Some geologists, however, deny that there is a break here, regard the Cleveland shale as Devonian, and draw the line at the base of the Berea sandstone. In the present state of knowledge the United States Geological Survey classifies the Cleveland and Bedford shales as Devonian or Mississippian and places the boundary of unqualified Mississippian at the base of the Berea. It is so shown on the accompanying map.

In the Doan Brook section the base of the Cleveland rests on very soft and disintegrated Chagrin shale with sharp, even contact. There is no trace of the hard beds containing fossils that appear on the south and east. In Mill Creek the contact is similar, and the Cleveland is underlain by a large thickness of soft shale from which sand beds are entirely absent. The contact is very slightly wavy. At Bedford about 1 foot of similar shale lies below the contact, underneath which occurs several feet of sandy shale and at intervals a band of flags containing Chagrin fossils, sediments unlike any found on Doan Brook or Mill Creek. At the base of the Cleveland is an intermittent marcasite band, ranging in thickness from 2 inches to a thin film and conforming to the slightly irregular surface of the underlying shale. On Brandywine Creek there is an even greater thickness of these upper sandy fossiliferous beds at the top of the Chagrin, and the sharp Cleveland contact is on a solid sandstone bed nearly a foot thick. On Ninemile and Euclid Creeks these upper sandy fossiliferous beds are wholly absent, and the Cleveland rests on soft barren shale that contains a few thin layers of flat concretions. The contact is very sharp, but the base is slightly wavy. The thin basal marcasite layer is very persistent but ranges in thickness from 1 inch down to a mere film. Below it is a persistent but very thin streak of yellow clay, and below that the soft Chagrin shale. Many other sections could be cited to show variations from place to place similar to these.

Emphasis is placed on the facts that the upper sandy fossiliferous beds of the Chagrin are confined to sections in which the thickness of the Cleveland is less than 40 feet and that they are absent in sections like those between and including Doan Brook and Euclid Creek, where this thickness is from 40 to 60 feet and where both sand and fossils are absent. This condition indicates that in these sections certain beds elsewhere present are lacking, or that the Cleveland rests on different horizons of the Chagrin from place to place.

The Big Creek and Rocky River sections are in the zone of rapid thickening of the Cleveland by additions at its base; the additions are chiefly black shale but include a few bands of blue fissile shale. The Chagrin beneath becomes much more sandy than at Cleveland and Euclid. There is no question as to the distinctness of the two formations at the contact, which is everywhere sharp. The contact is usually at the top of one of the flagstone bands but drops from one such band to another successively in passing west, and locally the Cleveland rests on soft shale. Where it rests on shale the thin streak of yellow clay is usually present between the two, and the variable marcasite basal layer of the Cleveland is present in many places also, with its characteristic oolitelike marcasite grains. Even where the Cleveland lies on flagstone a film of yellow clay in some places intervenes between this and the black shale, and the marcasite layer also appears here and there. The evidence is fairly convincing that the Cleveland rests on different beds of the Chagrin from place to place or lies on a surface beveled off by erosion before it was deposited.

In the sections west of the Rocky River (Dover Bay, Cahoon and Porter Creeks, Eagle Cliff, and Avon Point) it is very difficult to determine the actual base of the Cleveland shale, because the beds added to the base of the Cleveland contain much blue shale and some flagstone, and at the same time blackish shales appear in the Chagrin, so that there is no sharp, lithologic break, as there is farther east. Yet in all these sections (with one possible exception) a break was located at a contact between a band of black shale above and a blue shale or flagstone below, marked by a streak of yellow clay and an intermittent marcasite band, as in the sections above described. The crustacean *Spathiocaris cushingi* is found in every section in the black shale down to the horizon of this break and is not found below it so far as the writer has been able to discover. The plant fragments in the shales above and below this line represent different forms. This break is 22 feet above the lake level on Cahoon Creek and from 2 to 8 feet above it in the cliff sections around Avon Point. Careful scrutiny is needed to locate it, and it may easily escape recognition.

This break is thought by the writer to be the local representative of the widespread break farther south at the base of the Chattanooga shale and to be a more significant break than those at the base of the Bedford shale and of the Berea sandstone described below.

### BEDFORD SHALE

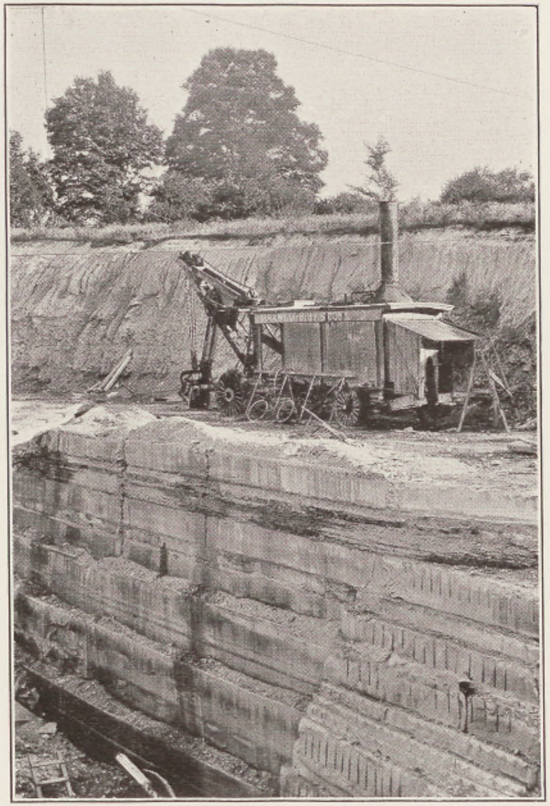
*Definition.*—The Bedford shale was named by J. S. Newberry from the very excellent section of the formation that is exposed in the gorge of Tinkers Creek at Bedford. It there has a thickness of about 85 feet and is composed chiefly of soft blue shale, in which are

CLIFF OF CHAGRIN SHALE NEAR EUCLID CREEK, THREE-FOURTHS OF A MILE SOUTH OF EUCLID

View looking east. The cliff is about 80 feet high. The thin harder bands here and there and the shallow rainwash gullies show plainly. At the top the base of the black Cleveland shale appears.

*A*. SHALE BANK OF CLEVELAND BRICK & CLAY CO. NEAR CLEVELAND

Section in foreground shows 20 feet of black and blue Cleveland shale and 88 feet of Chagrin shale.

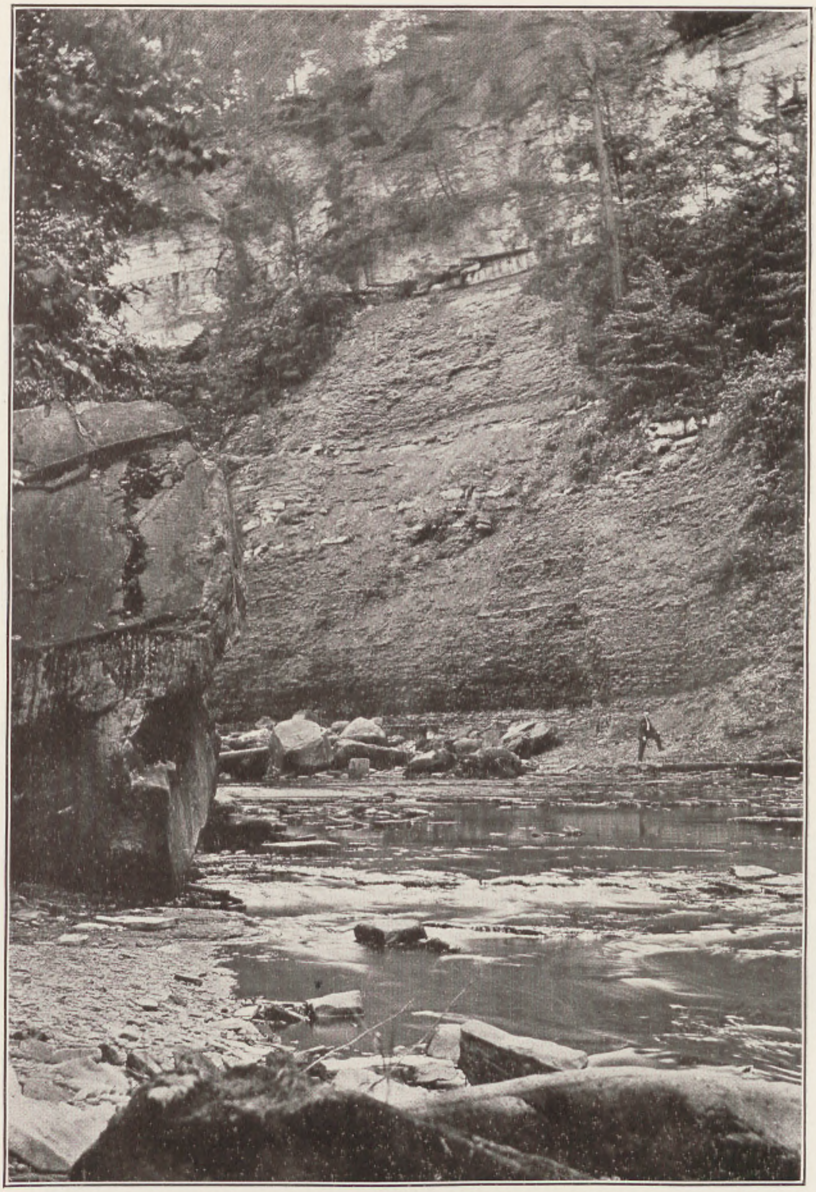


*B*. QUARRY IN "EUCLID BLUESTONE" AT SOUTH EUCLID

View shows about 20 feet of drift and Bedford shale, which must be stripped, and over 30 feet of bluestone; also two different methods of quarrying. On the right drills were used, on the left channeling machines.

BEDFORD SHALE IN OLD QUARRY ON EUCLID CREEK, 1¼ MILES NORTH OF SOUTH EUCLID

View looking southeast. About 12 feet of the "Euclid bluestone" shows above the water level, one massive layer, overlain by thinner layers with shale partings; above lies 20 feet of soft blue shale, with here and there thin bands of flags or concretions. Above the uppermost of these bands the shale is red, soft, and homogeneous and passes upward into the thin sheet of overlying boulder clay.



BEDFORD SHALE AT TYPE LOCALITY, TINKERS CREEK, BEDFORD

Bank about 90 feet high, showing 20 feet of the Berea sandstone above and nearly the entire thickness of the Bedford beneath, consisting of blue shale with thin bands of flags or concretions here and there, but with no bluestone and no red shale in the section. On the left is seen the edge of one of the large downfallen blocks of Berea sandstone.

BEDFORD SHALE 2 MILES SOUTH-SOUTHEAST OF BROOKLYN

Shows beds of shale with strong dip to the right, overlain by horizontal shales; a thin sandstone layer lies at the summit of the tipped shales.

LEDGES ON TINKERS CREEK JUST WEST OF PENNSYLVANIA RAILROAD BRIDGE

View looking south. Shows the upper 40 feet of the Berea sandstone, overlain by the Orangeville shale, including at base 6 feet of shale representing the Sunbury shale, overlain in turn by 8 feet of the Aurora sandstone member of the Orangeville shale.

at intervals bands of thin flagstone and of hard, calcareous concretions. Elsewhere it differs materially from this description, and it is the most variable formation in the section.

*Distribution and occurrence.*—In the Cleveland and Euclid quadrangles excellent exposures of the entire thickness of the formation are found along many streams, notably Euclid, Tinkers, Brandywine, and Skinners Creeks. It is also excellently shown on Big Creek and the two branches of the Rocky River. East of the Cuyahoga a sandstone (the Euclid sandstone lentil) within the Bedford formation caps a terrace averaging half a mile in breadth, the lowest and northernmost one of the three that here constitute the escarpment. This terrace extends up the Cuyahoga Valley as an obscure shoulder on each wall, though narrower and less prominent than at the escarpment front. The sandstone is present as far west as the southwest headwater tributary of Big Creek in the Berea quadrangle, but its terrace has disappeared, and the Bedford forms the foot of the escarpment front and part of the Erie Plain, with a breadth of outcrop of a mile or more. West of the Rocky River the formation lies wholly within the Erie Plain and is so completely covered with drift that little can be told about it.

*Character.*—The Bedford is essentially a soft clay shale, very similar in character to the soft shales of the Chagrin. Much of it is blue, much of it is dull red, and locally some of it is black. West of the Cuyahoga the larger part of the shale is red; east of the river blue prevails. Where both colors occur in the same section the red shale is generally above the blue. The black shale is found only at the base of the formation. Much of the rock is exceedingly dense and firm when freshly exposed and is lacking in fissility, so much so that the excavator usually calls the rock soapstone, as he does also the Chagrin shale. It weathers with extreme rapidity, chiefly by checking into irregular fragments that suggest shrinkage-cracked mud. Fissility develops in some beds but hardly at all in others, and all the material is exceedingly soft and tender when wet, though it becomes fairly firm on thorough drying. The red shale is even weaker than the blue, so that its characteristic occurrence in outcrop is as a red mud, and hand specimens of the firm rock can be collected only when an excavation is being made.

Interbedded with the shales are bands of blue-gray sandstone and of hard dark-gray concretions. (See pl. 3.) The concretionary bands occur at all horizons but are more common near the base. They consist of fine sand and clay, thoroughly cemented by lime and iron carbonates, and there is much variation in the relative amounts of lime and of sand. Mostly they are fine grained and exceedingly hard and flinty. They weather reddish.

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The sandstone bands are usually from 3 to 10 inches thick and occur singly, separated by different thicknesses of shale. Locally they thicken, the interbedded shales becoming very thin, and form a sandstone member from 10 to 25 feet thick in which some very massive beds occur. The stone is light blue-gray, is very fine grained, and contains a considerable quantity of argillaceous matter and a little calcareous matter. The surface of most of the beds is beautifully ripple marked. Such a sandstone (the Euclid sandstone lentil), about 20 feet thick, occurs across the eastern part of the city of Cleveland. It is known commercially as the Euclid bluestone. It extends from Euclid southwestward into and up the Cuyahoga Valley beyond Brecksville but is missing between Newburg and Bedford. It contains massive beds 2 or 3 feet thick, makes an admirable flagstone, and in past years was largely quarried for that purpose, particularly at Euclid. (See pls. 2, *B*, and 3.) It lies near the base of the formation, with 2 to 10 feet of blue shale and thin flagstone between it and the Cleveland. Shallow sand channels descend from its base into the shale beneath, and many of them show rounded flow markings very beautifully. The stone contains many concretions, some of marcasite and some of gray lime-iron composition.

In and west of Cleveland many sections show some black shale in the basal part of the Bedford. In the vicinity of Doan Brook a basal bed, about 6 inches thick, of dense gray-black nonfissile shale, which is coarser grained than the ordinary Cleveland shale, seems to grade upward into the overlying blue shale, has a sharp contact with the ordinary Cleveland beneath, and carries invertebrate fossils that are also found in the next succeeding shales with the typical Bedford fauna. It has every appearance of being reworked black mud, and on this account it is included in the Bedford shale instead of in the Cleveland. On Mill Creek is a similar zone only 2 or 3 inches thick, which has already been described. The greatest known thickness of these black beds in the Bedford is found in the Skinners Run section, where they contain sandstone bands and lenses identical in character with the usual Bedford sandstones and have a thickness of more than 25 feet.

*Variation.*—The Bedford shale shows great variation in character and in thickness from place to place within the district. The Euclid Creek sections show about 15 feet of basal blue shale with thin flags, on which lies about 25 feet of Euclid sandstone, capped by 30 to 50 feet of shale, the upper 10 to 15 feet of which is usually red and the remainder blue. (See pl. 4.) The Doan Brook and Mill Creek sections are very similar. The Tinkers Creek section differs materially. No red shale is present, and the whole 85 feet consists of blue shale with thin courses of flagstone and here and there a concretionary band. The zone from 40 to 65 feet above the base contains much more sandstone than the rest, but the beds all alternate with shale. (See pl. 4.) A few miles farther south the small creeks show an even more sandy zone about 30 feet above the base of the formation. On Brandywine Creek the Bedford is only 65 feet thick, the basal 50 feet being nearly all blue shale, upon which lies 7 feet of massive sandstone and 9 feet of alternating shale and sandstone, with the Berea directly above. On Chippewa Creek the sandstone is much lower, more in the position of the Euclid lentil, and the top of the formation is red shale.

In strong contrast to these stand the sections farther west, of which those on Skinners Run and the Rocky River will serve as examples. On Skinners Run the Bedford is about 90 feet thick. The lower 25 feet consists chiefly of black shale, containing many irregular bands and lenses of blue sandstone, large concretions, and much marcasite. The beds are greatly disturbed. The sandstone beds decrease laterally to thin sheets of sandy material that may wholly pinch out within several yards. Vertical shoots run off from these beds along joint cracks and much resemble narrow dikes of igneous rock, but the material in them is a mixture of sand and marcasite, the marcasite in many places in considerable masses. The shales dip in all directions and show numerous small folds and faults, but none of these disturbances involve a great thickness of the rock, and the overlying and underlying shale is not affected. (See pl. 5.) These conditions indicate that the disturbance took place at the time of deposition and was probably due to the currents that brought in the sands. Above this black shale lies 20 feet of blue shale and flags succeeded by about 50 feet of soft red shale.

The Rocky River section is very similar to this one, the Bedford having a thickness of about 80 feet. The lower 25 feet consists of black shale, with a blue band midway, and at the top and bottom a bed of calcareous sandstone that contains Bedford fossils. Above lies 15 feet of blue shale, capped by 40 to 45 feet of soft red shale.

The thickness of the formation within the district ranges from 40 to 110 feet. The greater part of this difference is due to irregular wearing away of the upper beds by the currents that brought in the sands of the Berea formation.

*Fossils.*—Most of the Bedford shale is barren of fossil remains, but in most sections rather abundant fossils may be found in the basal few feet. In these barren shale formations search for fossils is most likely to meet with success just above and just below the black Cleveland shale. The best localities for collecting Bedford fossils in the district are in Tinkers and Brandywine creeks, where they occur in soft shale and in hard concretions, and in the branches of Euclid Creek, where they occur in somewhat calcareous, sandy shale. In the soft shale many shells are present, but they are all crushed. In the sandy shale the fossils have kept their shape better, but the shell is gone. Very few are found in the sandstones. They would be plentiful at Cleveland if the base of the formation were well exposed, and large collections may be made from artificial excavations, such as the new Baldwin Reservoir.

The fauna has long been known but has never been thoroughly studied and described. As the bulk of the forms are of undescribed species, only a very imperfect list of them can be given. The pelecypods are chiefly represented by species that have a strong likeness to Devonian (Hamilton) forms. Similar forms are, however, found in the undoubted Mississippian elsewhere. The brachiopods do not as strongly suggest the Devonian.

Lingula meeki?
Lingula sp. (large form).
Orbiculoidea herzeri.
Orbiculoidea sp.
Pholidops n. sp.
Schuchertella herricki.
Schuchertella morsei.
Camarotoechia kentuckiensis.
Camarotoechia sp.
Chonetes n. sp.
Productella pyxidata?
Strophalosia sp.
Rhipidomella n. sp.
Cranaena n. sp.
Cryptonella n. sp.
Nucleospira n. sp.
Camarospira? sp.
Syringothyris carteri?
Delthyris n. sp.
Athyris aff. A. lamellosa.
Ambocoelia norwoodi.
Palaeoneilo bedfordensis.
Leda n. sp.
Parallelodon irvinensis.
Pterinopecten? n. sp.
Pterinopecten? n. sp.
Cypricardella n. sp.
Cypricardinia sp.
Sphenotus sp.
Pholadella sp.
Ptychodesma? n. sp.
Prothyris n. sp.
Bellerophon sp.
Tropidodiscus sp.
Pleurotomaria sp.
Bembexia sp.
Platyceras sp.
Loxonema sp.
Conularia aff. C. newberryi.
Orthoceras sp.
Goniatites sp.
Brachymetopus sp.

Several ostracodes occur; also crinoids, too badly preserved to be determinable; and rarely remains of fishes. One specimen of a hexactinellid sponge has been found. Near the base of the formation, on Mill Creek, numerous specimens of *Lycopodites* are found in a single layer.

The basal, fossiliferous layer on Euclid Creek is a hard sandy calcareous shale, and the fauna shows a quite different expression there compared with that in the soft shale at Cleveland and Bedford. The species are the same but differ much in abundance in the two localities, a difference which seems certainly due to the contrasted conditions of sedimentation in the two places.

*Break at base of Bedford shale.*—At the base of the Bedford shale in many sections is the zone described above, of differing thickness, which consists of reworked black shale from the Cleveland below. This zone is more likely to be present where the basal Bedford is sandy than where it consists of soft shale. The greatest known thickness of this zone is on Skinners Run, but nearly all the sections at and west of

Cleveland show some such material. At other localities—Tinkers and Brandywine Creeks, for example—where the Bedford begins with soft shale, no reworked black shale is shown, but instead a very sharp contact and the basal blue shale is a compact bed that is composed in very large part of shell fragments in a mud matrix. Among the fragments are many whole shells of invertebrates that evidently lived on the bottom composed of the fragments. A considerable pause in deposition is indicated, during which the fauna came in and lived for a considerable time in clear water, the shells being broken up and accumulating on the bottom. The writer has failed to discover, however, any evidence that the sea withdrew and land conditions prevailed during this interval, though it is believed that such were the conditions between the Chagrin and Cleveland epochs. Deposition was interrupted before the Bedford shale was laid down, but the interruption was unaccompanied by emergence.

## CARBONIFEROUS SYSTEM

By H. P. Cushing

### *MISSISSIPPIAN SERIES*

#### BEREA SANDSTONE

*Definition.*—The Berea sandstone was named by Newberry from the village of Berea, which is situated on this formation and where the rock has been much quarried for many years. It is here a coarse sandstone formation with a general thickness of 60 feet but becomes locally much thicker. Many layers are cross-bedded, many are ripple marked, and the lower part of the formation is thicker bedded and more massive than the upper.

*Distribution and occurrence.*—The Berea is the lowest persistent formation in the district that strongly resists erosion. It owes to this quality its position as the capstone of one of the terraces of the escarpment that overlooks the Erie Plain. East of the Cuyahoga it has an average thickness of 50 feet and its belt of outcrop is about half a mile wide; it forms a prominent terrace with a somewhat irregular margin along the 900-foot contour, fronting Lake Erie. Similar terraces are found on both sides of the Cuyahoga Valley. West of the Rocky River the formation thickens and its altitude diminishes; hence the breadth of outcrop increases to several miles.

The chief outcrops of the Berea, as of the other formations, are along the streams. The principal streams flow in shallow valleys of slight descent across the formation and fall over its northern edge into gorges whose walls are shale below and sandstone above. The weak shales are rapidly eaten back, and many sandstone ledges overhang their support. These ledges eventually become undermined, and large blocks break off and work their way down the banks and clog the stream. Such blocks are particularly abundant on Chippewa Creek.

Besides the creek exposures the Berea is exposed in many more places in the interstream areas than most of the other formations, because of its resistance to erosion. Outcrops are especially numerous along its escarpment fronts. It has also been exposed in very many artificial openings, such as quarries and railroad and road cuts.

*Character and thickness.*—In this district the Berea is composed chiefly of medium-coarse pure quartz sand, loosely cemented into what is known as a clay-bond sandstone. The cementation is nowhere complete and differs considerably in closeness from bed to bed, so that the rock as a whole is rather porous and is heavily charged with water underground. Some layers are very slightly cemented. The mason finds the rock easy to cut and dress. The usual color is light gray, but some beds are specked with yellow-brown, and in some localities much of the rock is of this color. Over much of the district the formation can be separated into a lower division made up chiefly of thick, massive beds and an upper division of thin beds. Cross-bedding is a prominent feature nearly everywhere, and locally at least half the thickness possesses this character. (See pl. 6.)

Under cover gray is the prevailing color of the rock, with the iron in the form of pyrite; above the ground water the pyrite has oxidized and stained the rock light or deep brown, according to the amount present. Many beds are ripple marked; some are slightly pebbly, with all the pebbles of quartz; some contain a few clay-iron concretions; and rarely nodules of soft, compact clay occur, evidently deposited as clay balls by the currents that transported the sand.

The underground water in the formation is confined there because of impervious shales above and below; hence many springs issue wherever the base crops out. The spring waters are likely to be mineralized; many deposit limonite, a less number are strongly sulphurous, and at several localities (Brandywine Creek, Tinkers Creek) the water is so strongly charged with calcium carbonate that it has formed considerable deposits of travertine at the base of the sandstone.

The formation ranges in thickness from as little as 5 feet (Boston Mills) to as much as 150 feet (Berea) within the area shown on the map and passes both those limits in near-by territory. Locally at Akron it is entirely absent, and at Amherst it is at least 225 feet thick. In many places great variation in thickness is shown within a short distance, owing to irregularity of its base. This feature is much more conspicuous in the Berea quadrangle than in the Cleveland quadrangle.

*Fossils.*—The Berea sandstone in places contains plant fragments in abundance, especially in the upper part of the formation, but only at a few localities does it contain animal remains. At Cleveland the surface of one bed of the stone is a mass of the plant fragments. The plant tissue has usually been altered to a thin film of black, coaly material. Here and there recognizable leaves of plants are found, such as *Annularia longifolia*?, long ago reported by Newberry from Bedford and frequently found since.

Many specimens of a single species of paleoniscid fish, *Gonatodus brainerdi*, have been found in the quarries at Chagrin Falls, and rarely single specimens have been forthcoming elsewhere, as at Berea, Newburg, and Independence. The quarries at Chagrin Falls are in the upper, thin-bedded portion of the formation, and the fossil fishes are abundant on the surface of one particular layer and there only.

Very rarely single specimens of marine brachiopods are found in the upper, thin beds of the formation. The writer has seen three or four. All were badly worn and broken and appeared as if they had undergone much transportation by waves or currents.

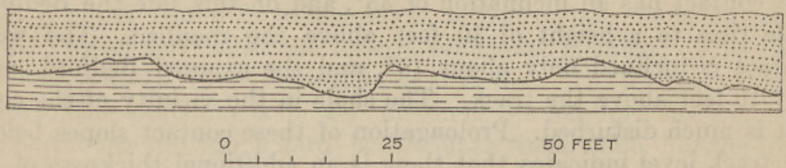



FIGURE 4.—Contact of Berea sandstone on Bedford shale in railroad cut in Newburg Township, Cuyahoga County. Scale, 1 inch=30 feet

It is thus seen that the fossils of the Berea in northern Ohio are not marine forms, and their evidence aids in the determination that the Berea here is not a marine formation.

*Break at base of Berea sandstone.*—In nearly all sections the Berea rests on the Bedford shale with prominent erosional discordance. Wherever good exposures of the contact occur, it is seen to be irregular, in many places highly so. The upper surface of the Bedford has been considerably eroded by currents, and the eroded channels have been filled with Berea sand. Most of these channels are shallow but deep ones occur, and these are largest and most abundant in the district west of Cleveland. (See pl. 7.)

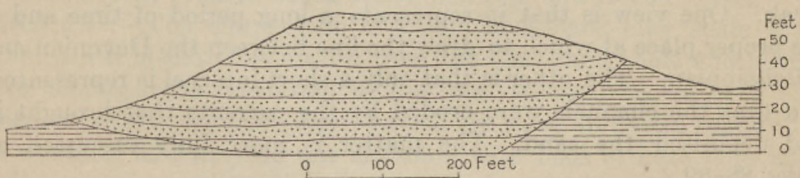



FIGURE 5.—Berea-Bedford contact in cut on the Belt Line Railroad 2 miles southwest of Brooklyn, showing a Berea channel more than 30 feet deep cut in the shale

The minor irregularities of the base are well shown in a long cut of the Pittsburgh & Lake Erie Railroad high on the east slope of the valley of the Cuyahoga east of Willow. The exposure is no longer very satisfactory, owing to the rapidity with which the Bedford shale decomposes and becomes covered with vegetation, yet it still shows the irregular base of the sandstone. (See fig. 4.)

One of the larger channels is sectioned by a deep cut along the Belt Line Railroad 2 miles southeast of Brooklyn, near the west margin of the Cleveland quadrangle. A long, narrow point of Berea sandstone here projects northward more than half a mile beyond the main edge of the formation, and the railroad cut passes through it from west to east. The high point is a prominent topographic feature. A sketch of the section shown in the cut is given in Figure 5. Midway of the cut is Berea sandstone, descending below the level of the roadbed. At the sides red Bedford shale appears underneath the Berea and rises in level until it makes the full height of the cut. The east contact has an inclination of 35°, and on this side the Bedford shale rises to a height of 30 feet above the roadbed. The west contact is inclined only about 10°, and the exposed Bedford rises only 10 feet above the track. The shale in the vicinity of the contact is much disturbed. Prolongation of these contact slopes below the track level indicates that there is an additional thickness of 10 to 20 feet of Berea sandstone below ground in the center of the cut. As the exposures stand they show a channel cut into the shales to a depth of 30 to 50 feet and having a width of about 100 yards at the level of the roadbed. The greater steepness of the east side indicates that the main current was against that bank.

Channels of this type, cut out of the shale and filled with Berea sand, occur as far east as the Chagrin River but are most abundant and deepest in Lorain, Erie, and Huron Counties. Here many of them are cut wholly through the Bedford shale, so that the Berea rests on Cleveland shale in the channel bottoms, and the Bedford occurs only between the channels.

Geologists are not yet in agreement as to the significance of this break. One view is that it represents a long period of time and is the proper place at which to draw the line between the Devonian and Mississippian. The other is that only a short interval is represented, and that the channels were eroded by the currents that brought in and deposited the sand. The matter is more fully discussed on pages 88–89.

### CUYAHOGA GROUP

In this area the rocks long known as the Cuyahoga shale are divided into three units, called in ascending order Orangeville shale, Sharpsville sandstone, and Meadville shale. The type localities of these subdivisions are in the northeast corner of Ohio and the northwestern part of Pennsylvania. The subdivisions are quite distinct and are here mapped separately. The Cuyahoga is therefore in this, its typical area, elevated to the rank of a group, and the subdivisions are treated as formations, although in western Pennsylvania they have heretofore been treated as members. The Cuyahoga as generally recognized in Ohio overlies the black Sunbury shale (see pls. 22, 23), a thin representative of which is present in the basal part of the Orangeville shale, but it is here too thin to separate from the Cuyahoga rocks.

### ORANGEVILLE SHALE

*Definition.*—The Orangeville shale was named by I. C. White from the village of Orangeville, on the Ohio-Pennsylvania line in Trumbull County, where it consists chiefly of soft blackish shale but where only a part of the thickness is shown. In the Cleveland district it forms the basal portion of the rocks named Cuyahoga shale by Newberry—here called Cuyahoga group—and has a thickness of about 125 feet. It is very homogeneous except that it carries a fairly persistent sandstone member from 6 to 10 feet thick, 10 feet or less above the base, which Prosser has called the Aurora sandstone member. This bed, however, is absent in some sections, as at Berea. The few feet of shale beneath this sandstone is on the horizon of the Sunbury shale of central and southern Ohio, a hard, brittle black fissile shale, but the zone is much thinner in the Cleveland district, is usually neither very black nor very fissile or brittle, and is not easily separable from the overlying Cuyahoga beds.

*Distribution and occurrence.*—The Orangeville shale extends across the district from northeast to southwest in a belt from 1 to 5 miles wide, forming a gentle drift-covered slope that rises from the southerly edge of the Berea terrace on the lower slope of the Portage escarpment. The Cuyahoga and Rocky River Valleys notch its front and turn its u tcrop up the valleys, and the best exhibitions of the formation are found in the valleys of the tributary creeks. On Chippewa and Brandywine Creeks practically every inch of it is exposed. Good exposures of part of the formation occur on Skinners Run, Big Creek, Baldwin Creek, Tinkers Creek above Bedford, and Euclid Creek.

*Character.*—The Orangeville is a soft blue-black clay shale that contains less bituminous matter than the Cleveland shale and is the most homogeneous formation in the local section. Some beds are fissile and others are more solid, but all are weak and yield rapidly to the weather, and they do not alternate with beds of hard flags and hard concretions, like the other shale formations. Hence where exposed in high cliffs, as along Chippewa and Brandywine Creeks, the shale becomes deeply gullied by the rains. (See pl. 8, *A*.) There is an average thickness of 100 feet of beds of this character. Only in the basal 15 to 20 feet and in a similar zone at the top is any variation found.

The basal layer of the formation, in few places more than 3 inches thick, is a very hard black layer consisting largely of sand cemented by pyrite. It lies closely fitted to the top of the Berea, with which it has usually been classed, and seems to be everywhere present, notwithstanding its thinness. It is the only bed in this group that suggests a transition from sand to mud; the pyrite marks it as a basal bed rather than a top layer, and its fossils also indicate that it belongs here rather than to the Berea.

The Aurora sandstone member consists of blue-gray fine-grained sandstone, much of it weathering yellowish brown, and ranging in thickness from 10 feet to a knife-edge. The shale between it and the Berea below is also variable. In some places it is black and slaty and has the Sunbury character; in others it shows this character only for the basal foot or so; and in still others it consists entirely of soft dark-blue to gray clay shale. Thus at Berea the basal shale is black for a thickness of at least 10 feet and the Aurora sandstone is absent; at Bedford at least 8 feet of the Aurora is present, separated from the Berea by 6 feet of shale, which is nearly all blue or gray and quite unlike the Sunbury; on Chippewa Creek the sandstone is only 5 feet thick and has shale partings, and the 6 feet of shale below is almost black and like the Sunbury at the base but has much blue shale above.

*Fossils.*—The Orangeville as a whole is almost barren of fossils, but they may be found sparingly at all horizons, and the forms that occur are of the same types as those of the Cleveland shale. *Lingula melie* and *Orbiculoidea herzeri* are most common in the basal part of the shale and at some localities are very abundant, as at Berea; but they are found here and there at all horizons. Brandywine Creek is the best-known collecting place for the higher beds. *Orbiculoidea* is the most common fossil, but fish scales and spines also occur, and conodonts are found, though they are chiefly confined to the small thickness of shale under the Aurora sandstone. The sandstone itself is sparingly fossiliferous and from Bedford has furnished specimens of *Orbiculoidea herzeri* and fragments of a hexactinellid sponge. The basal black pyritiferous layer, heretofore assigned to the Berea, also contains fossils, chiefly fishes. From this layer and from the shale just above it at Berea have been obtained the following:

Ctenacanthus formosus.
Ctenacanthus clarki.
Ctenacanthus angustus.
Cladodus pattersoni.
Physonemus tumidus.
Mazodus kepleri.

SHARPSVILLE SANDSTONE

*Definition.*—The Sharpsville formation was named by I. C. White from the village of Sharpsville, on the Shenango River in Mercer County, Pa., not far from Orangeville and the Ohio line. It consists of gray-blue to gray-brown sandstone in beds from 1 to 2 feet thick, alternating with thin layers of gray shale and with a thin bed of blue limestone near the base, the whole having a thickness of 65 feet. This zone of sandstone, directly overlying the Orangeville shale, is found throughout northern Ohio, and there is no question about its continuity and identity with the sandstone at Sharpsville. It is the middle formation of the Cuyahoga group.

*Distribution and occurrence.*—The Sharpsville has no great breadth of outcrop, because it is a thin formation. It forms a narrow terrace, generally covered with drift, from 1 to 3 miles back from the Berea terrace and about 125 feet above it. The exposures are confined to the banks and beds of streams and many are poor, as the formation lies well toward the headwaters of most of the brooks. The best exposures of the formation are on Brandywine Creek at Little York, where a broad terrace has been developed on the formation and the creek channel has been artificially deepened through it. Chippewa Creek, Baker Creek, and Skinners Run also show the formation well.

*Character and thickness.*—The Sharpsville has a thickness of 25 to 50 feet in the Cleveland district and is thinner and more shaly than in the type locality. Neither the upper nor the lower boundary is sharp; the underlying Orangeville apparently is transitional into it, and the formation merges into the overlying Meadville shale. The lower 15 feet or more is commonly very shaly, consisting of blue fissile shales with thin bands of blue-gray sandstone and of sandy shale. The upper portion of the formation consists chiefly of sandstone with thin shale partings between the beds. (See pl. 8, *B*.) These sandstones are prevailingly gray and in beds from 2 to 18 inches thick. The sand is fine grained, is somewhat micaceous, and has a small percentage of argillaceous and calcareous matter. There is much marcasite in the formation, and the shells of many of the fossils are wholly replaced by this mineral. Considerable zinc blende occurs in the shell cavities. Some of the stone is reddish, and the red bands are most conspicuous in the central parts of the thicker beds, the margins of which remain blue. The sandy shales are blue-gray, very sandy, and very finely laminated, containing many mica scales.

A detailed section of the formation at the Brandywine Creek exposure will give a better idea of it than a generalized description.

*Section of the Sharpsville sandstone at Little York*

| | Feet |
|---|---|
| Somewhat massive sandstone, shale partings; mostly gray but thicker layers partly red; much marcasite and some sphalerite, especially in association with the fossils; at base a 2-foot layer | 11 |
| Thin gray flags alternating with sandy shale; fossils common but poorly preserved | 8 |
| Bluish fissile shale and laminated sandy shale, containing thin layers of blue-gray flagstone, with a 3-inch sandstone layer at the base | 11 |
| Mostly blue fissile shale, with thin layers of sandy shale and a 2-inch layer of blue sandstone at base. Base of Sharpsville | 5 |
| Blue-black soft shale (Orangeville shale). | |
| | 35 |

*Fossils.*—In most exposures the Sharpsville sandstone contains few fossils and those are in a poor state of preservation. But at Little York, on Brandywine Creek, fossils are rather abundant and in some layers are well preserved. A fauna of about two dozen species has been obtained at this point, but it has not yet been thoroughly studied and can only be listed. Some of the species seem identical with those found in the Bedford shale—the *Parallelodon* and *Tropidodiscus*, for example.

Chonetes sp.
Rhipidomella sp.
Camarotoechia sp.
Spirifer cf. S. centronatus.
Delthyris sp.
Syringothyris sp.
Productella sp.
Ambocoelia sp.
Lingulodiscina cf. L. newberryi.
Lingula sp.
Parallelodon irvinensis.
Nucula sp.
Palaeoneilo sp.
Cypricardella sp.
Nuculana sp.
Grammysia cuyahoga.
Bellerophon cf. B. jeffersonensis.
Tropidodiscus cyrtolites.
Orthoceras sp.

MEADVILLE SHALE

*Definition.*—The name Meadville shale, given by I. C. White, has long been in use in reports on the geology of western Pennsylvania, where it has been applied to the shales resting on the Sharpsville sandstone. The formation was named for its occurrence at Meadville, Crawford County, Pa. In the Cleveland district it has a thickness of 30 to 250 feet and consists of alternating blue shale, thin sandstone, and sandy limestone. It forms the upper half of the Cuyahoga shale of Newberry in northern Ohio.

*Occurrence and thickness.*—The Meadville forms the upper and steeper half of the long, gentle slope that stretches down from the preserved fragments of the Appalachian Plateaus or Pottsville terrace to the Berea terrace. It occupies an area of considerable size between the Cuyahoga River and the West Branch of the Rocky River, in the southwestern part of the Cleveland quadrangle and southeastern part of the Berea quadrangle. Owing to heavy drift covering and to high altitude only the headwater portions of the streams lie across it, so that good exposures are scarce, and no continuous section exists within the quadrangles. The best sections are those on Baker Creek, Big Brook, branches of Chippewa Creek, and small runs tributary to the Rocky River in Royalton Township. East of the Cuyahoga River the formation is much thinner than on the west side, and there are no exposures worthy of the name.

The thickness of the formation increases rapidly and unevenly from east to west. In Northfield and Warrensville Townships it is less than 100 feet; in Brunswick and Strongsville it is 200 feet or more. This variation is due to unequal pre-Pottsville erosion. (See section on unconformity at the base of the Sharon conglomerate, pp. 56–57.)

*Character.*—The Meadville consists of alternating beds of shale and sandstone. The shales range from soft clay shale to very sandy shale. The clay shales are generally blue to blue-black and fissile, but some beds are blocky and show little tendency to split. They are quite like the similar shales of the Bedford and Chagrin formations and were evidently deposited under similar conditions. The sandy shales are grayish blue and well laminated. Many layers of flattened hard lime-iron concretions, blue within but weathering reddish, alternate with these shales and are especially abundant in the lower 100 feet of the formation. Many of these concretions are exceedingly fine grained and flinty, and they are usually unfossiliferous; others are of somewhat coarser texture, and many of these contain excellently preserved fossils.

The flagstones throughout the formation are blue to gray, thin bedded, in places laminated, and generally micaceous. In the lower 100 feet they are subordinate in quantity to the shales, but in the higher part of the formation they equal or exceed the shales. Associated with them are beds of calcareous sandstone or sandy limestone, rather fine grained, usually very hard, gray to blue, but in may places tinged with red and weathering to red or yellow-brown. The more sandy beds weather to brown porous sandstones; the more calcareous beds to weak, friable fragments of iron-stained sand. These beds together with the flagstones constitute the bulk of the upper part of the formation.

*Fossils*.—The Meadville shale, unlike all other formations in these quadrangles, is very fossiliferous at many horizons. It contains an abundant and varied marine fauna or rather series of faunas, for there are several faunal zones in the formation, and many of the fossils are in an excellent state of preservation. They are less abundant in the lower beds than in the upper and occur chiefly in the concretions and the calcareous layers, but the soft shales and sandstones carry them also. The soft blue shales above the Sharpsville sandstone carry a fauna in which many of the species are very close to if not identical with the Bedford shale forms. Others are like the Sharpsville fossils. The faunas have never received thorough study, and the list of forms is therefore provisional and is not divided into zones. It is a long list yet is far from complete. Fragments of land plants are not uncommon in the same beds that contain the marine fossils.

Productella newberryi.
Productella aff. P. concentrica.
Productus ovatus.
Productus sp.
Productus n. sp.
Chonetes logani.
Chonetes cf. C. illinoisensis.
Leptaena analoga.
Schuchertella? sp.
Rhipidomella sp.
Spirifer centronatus.
Spirifer aff. S. centronatus.
Spirifer aff. S. striatiformis.
Cyrtina burlingtonensis.
Camarotoechia sp.
Hustedia sp.
Ambocoelia sp.
Reticularia sp.
Cliothyridina cf. C. obmaxima.
Centronella? cf. C. julia.
Cranaena sp.
Grammysia sp.
Edmondia burlingtonensis.
Edmondia sp.
Cypricardinia consimilis?
Sphenotus cf. S. valvulus.

Palaeoneilo truncata.
Palaeoneilo sp.
Nucula sp.
Nuculana sp.
Schizodus sp.
Mytilarca cf. M. occidentalis.
Pernopecten cf. P. cooperensis.
Pterinopecten cariniferus.
Aviculipecten sp.
Limatulina sp.
Oracardia? sp.
Tropidodiscus cyrtolites.
Buchanopsis sp.
Loxonema? sp.
Pleurotomaria textiligera.
Euomphalus sp.
Platyceras cornuforme.
Platyceras sp.
Platyceras sp.
Conularia newberryi.
Orthoceras sp.
Brachymetopus sp.
Dictyospongia sp.

In addition Bryozoa of several species are very numerous, and crinoids are abundant in places. Sixteen species of crinoids described from Richfield[4] may have been found within the south boundary of the Cleveland quadrangle and certainly were obtained within 3 or 4 miles of this boundary.

## PENNSYLVANIAN SERIES

### SHARON CONGLOMERATE

*Definition.*—The Sharon formation, of sandstone and conglomerate, which directly overlies the Mississippian rocks in Ohio and western Pennsylvania is the basal part of the Pottsville. It was named by the geologists of the Second Geological Survey of Pennsylvania from the exposures at Sharon, Mercer County, Pa.

*Distribution and occurrence.*—The Sharon conglomerate is found in disconnected patches or outliers that cap the highest hills in the quadrangles—those whose altitude exceeds 1,100 feet. Three such outliers are found on the east side of the Cuyahoga Valley—one in Warrensville, one in Northfield, and one in Boston; west of the valley are several in Brecksville, Richfield, Royalton, Hinckley, and Brunswick Townships. Many of them are very small islandlike remnants left behind in the general erosion of the formation and lie in front of its main mass, which is found in the quadrangles to the south and east. As the formation resists erosion much better than the Meadville underneath, these outliers stand boldly above the surrounding country, with steep fronts, along which many low ledges occur. Glacial drift is heavily banked against many of these fronts, especially on the north. The summits are thinly drift covered but in general sufficiently to hide the rock.

The best exposures of the Sharon within the quadrangles are those on the front of the promontory on the Strongsville-Brunswick township line, which are well shown along the Cleveland-Medina road as it climbs onto the Sharon surface. There are good exposures along the west bank of Furnace Run, in Brecksville, and along the East Branch of the Rocky River, in Hinckley. Other exposures show only a slight thickness of the formation. Far better ones occur just out-

[4] Ohio Geol. Survey, Paleontology, vol. 2, pp. 162–179, 1875.

side the quadrangles, and of these the Boston Ledges, just south, and the Chesterland Caves, a few miles east, are the most noteworthy.

The Sharon is heavily charged with underground water, and the springs that issue from its base along the outcrop fronts slowly weaken and wash away the shale beneath, slightly undermining the conglomerate, huge blocks of which settle somewhat. Frost action aids in pushing these blocks apart, cracks are widened into caves, and a tangle of blocks results, separated by passages of uneven widths. On the steep valley wall of the Cuyahoga at the Boston Ledges is a wonderfully fine example of the results.

*Character and thickness.*—The Sharon is composed of indurated sand and gravel. The ratio between the two varies greatly from place to place, but on the whole sandstone much exceeds conglomerate in quantity. The conglomerate is chiefly basal and exceptionally has a thickness of 50 feet, but it also appears as local lenses in the sandstone. (See pl. 9.) In some sections no conglomerate whatever appears and the formation consists of sandstone throughout. The upper portion is invariably sandstone. The sandstone is medium coarse, quartzose, and gray to brown. On the average it is a little coarser, more porous, and when freshly quarried less well cemented than the Berea. Much of it is irregularly bedded, and cross-bedding is common, both in the sandstone and in the conglomerate, which is massive and very poorly and unevenly bedded.

The conglomerate consists of rather well assorted pebbles, with the interstices filled with sand, except in a very few places. The pebbles are almost exclusively white quartz, not one in a hundred being of other material. The general size is 1 inch or less in diameter, and in a given bed there is a marked tendency for all the pebbles to approximate the same size. There is, however, much variation in abundance of the pebbles; in some beds they may not even be in contact, but may be embedded in sand; in others, especially in beds of small pebbles, they are so closely packed that there is but little interstitial sand. The cement in general is silica, but the basal bed is more commonly cemented by an iron mineral, limonite or pyrite, than it is by silica. Rarely the base has a calcareous cement. In places this bed has a thickness of many feet, particularly in channel fillings. The pebbles in it range from a diameter of 3 inches down to those of the smallest dimensions. Pebbles of other material than white quartz and variations in spacing are most common in this bed.

None of the pebbles in the conglomerate could have been derived from any of the local rocks beneath the conglomerate, in which white quartz of the type composing the pebbles is entirely absent. The nearest known source for them is the area of crystalline rock of Ontario, many miles to the north. They could also have come from the Piedmont rocks of Appalachia, but that source is still more remote.

Most of the conglomerate seems to occur as channel fillings in the sandstone, though in places it is difficult to recognize this form in the rather widespread basal conglomerate. In the higher beds of the formation, however, many channels of small size and unmistakable nature occur. Good examples of such channels occur within the Cleveland district, but others in the Mentor quadrangle, just to the east, are much better exposed. At Scotland, 2 miles east of Gates Mill and the Chagrin Valley, a quarry and a long road cut expose a thickness of nearly 50 feet of the Sharon, the section beginning at or near the base of the formation. The lowest beds are shown in the quarry (pl. 9) and have a thickness of 15 feet, the lower half to two-thirds of which consists of massive cross-bedded conglomerate, which passes into sandstone above. The road cut goes some 10 feet into the rock and is on a rising grade, so that altogether 35 feet of beds above those in the quarry are shown by it. Here the rock is chiefly sandstone, but from time to time while it was being deposited strong currents cut channels in the sand and filled them with gravel. These currents then shifted or ceased, and the deposition of sand was resumed and overspread the gravel-filled channel. The south edge of a channel 10 yards wide, whose bottom is below the level of the road gutter, is shown in Plate 10. Its sides have a slope of about 30° and border on sandstone for the full height of the cut, so that the depth of the channel must exceed 15 feet.

Here and there in the midst of the gravel in the channels balls of hard blue clay occur; the largest observed are 3 inches in diameter. They were clearly deposited at the same time as the pebbles and by the same agent.

As the Sharon is the summit formation of the district, its entire thickness is nowhere exposed; only the lowest 50 feet is to be seen. Its thickness is somewhat variable and is not accurately known; it certainly reaches 100 feet, perhaps 150 feet.

*Fossils.*—No fossils have been found in the Sharon in the Cleveland district except plant fragments, which are generally broken and water-worn. A few specimens that may be definitely referred to *Lepidodendron* or to *Sigillaria* have been seen.

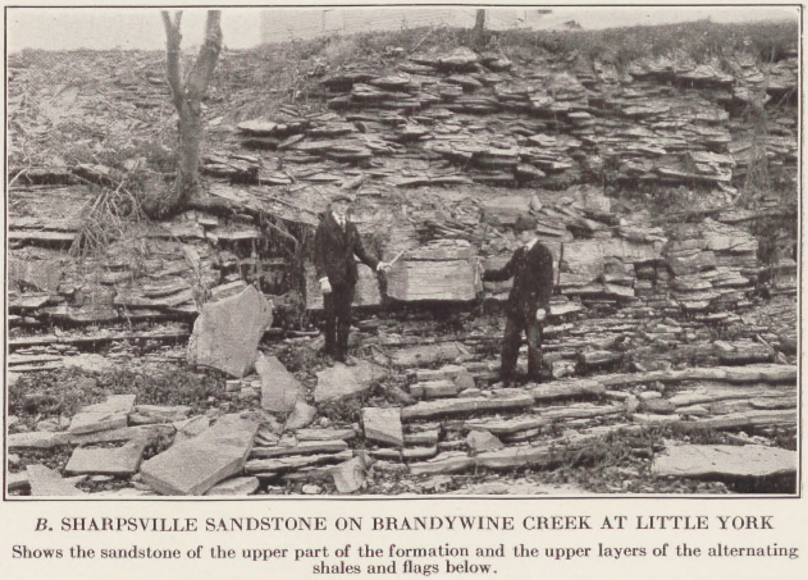
*Unconformity at base of Sharon conglomerate.*—The break between the Sharon conglomerate and the Mississippian formations beneath is the most conspicuous unconformity in the district. The conglomerate rests on the eroded edges of the slightly warped Mississippian beds. Throughout the Cleveland district it rests everywhere on the Meadville shale but on very different beds in different places. East of the Cuyahoga River, in Warrensville and Northfield Townships, only the lower 75 feet of the Meadville is present underneath the Sharon, whereas in Brecksville and Royalton Townships there is nearly 200 feet of the Meadville, and in Brunswick 250 feet. This discordance becomes more impressive when traced beyond the dis-

WEST CONTACT OF BEREA SANDSTONE ON BEDFORD RED SHALE IN CUT ON BELT LINE RAILROAD 2 MILES SOUTHWEST OF BROOKLYN

View looking north. On the right the base of the Berea is almost at the track level and passes beneath it a short distance beyond; on the left (west) it steadily rises until a height of 15 feet above the track is attained, and the Bedford reaches the surface of the ground on its westerly slope.

*A*. ORANGEVILLE SHALE CLIFF ABOUT 50 FEET HIGH, ON BRANDYWINE CREEK 1 MILE BELOW LITTLE YORK

Shows the homogeneous character of the shale and the manner in which it becomes gullied by rainwash.



*B*. SHARPSVILLE SANDSTONE ON BRANDYWINE CREEK AT LITTLE YORK

Shows the sandstone of the upper part of the formation and the upper layers of the alternating shales and flags below.

BASAL PORTION OF SHARON CONGLOMERATE IN QUARRY AT SCOTLAND, CHESTER TOWNSHIP, GEAUGA COUNTY

View looking north. Exposure consists chiefly of conglomerate but with sandstone above. Cross-bedding shows well at right.

VIEW IN ROAD CUT A SHORT DISTANCE NORTH OF THE QUARRY SHOWN IN PLATE 9

View looking east. Shows a thickness of 12 feet of somewhat higher beds; sandstone on right, conglomerate on left, the latter constituting the southern portion of a large gravel-filled channel in the sand 10 yards in width, with side slopes of about 30°. The entire channel shows excellently in the cut but can not be photographed as a whole.

trict. In the Chagrin Valley region, a few miles to the east, the Sharon rests on the upper part of the Orangeville shale, only 100 feet above the top of the Berea, and the Meadville and Sharpsville are absent. A little farther east the Meadville and Sharpsville reappear, and the interval between the Berea and the Sharon steadily increases eastward. Southwest from Cleveland this interval also becomes greater, and in Medina and Wayne Counties, within 25 miles of the south margin of the district, two additional formations, the Black Hand and the Logan, come in above the Meadville, and the interval between the Sharon and the Berea has expanded to about 1,000 feet, ten times its thickness in the Chagrin Valley.

The surface on which the Sharon rests also shows local irregularities, the conglomerate filling small channels cut in the underlying beds, of the usual type of the channels at the base of the Berea sandstone.

## QUATERNARY SYSTEM

By Frank Leverett

### PLEISTOCENE SERIES

#### GENERAL FEATURES

As the Cleveland district lies within the glaciated region of North America its indurated rock formations are mantled more or less completely by glacial deposits, consisting of till or boulder clay and associated beds of sand and gravel. (See pl. 21.) A part of the district was for a time covered by the waters of glacial lakes, which were held between the retreating ice border and the divide that now separates the St. Lawrence or Great Lakes drainage from that of the Ohio River. At the shores of the glacial lakes ridges of sandy gravel were formed, and on their beds deposits of sand and silt were laid down.

In the glacial epoch there were at least four distinct stages of glaciation, separated by intervals of deglaciation, in which the ice sheets withdrew. Each of these glacial stages is marked by a deposit of glacial drift, and the intervals of deglaciation are marked by soils and weathered surfaces of the several drifts. The oldest drift carries different names in the several parts of the glaciated region. It is called Jerseyan in the part east of the Alleghenies, and this name would probably apply in the Cleveland district, as it embraces drift that covered the district between the Alleghenies and Mississippi Valley as well as that in the district east of the Alleghenies, both laid down by ice from the Labrador part of the ice sheet. In the district west of the Mississippi the oldest drift has been called sub-Aftonian, pre-Kansan, and Nebraskan; the second is generally known as Kansan drift; the third from the Labrador part of the ice sheet, Illinoian, the third from the Keewatin part, Iowan; and the drift of the latest glacial stage is called the Wisconsin.

### PRE-ILLINOIAN DRIFT (KANSAN?)

An old drift is exposed in northwestern Pennsylvania [4a] outside the later drifts, but its relation to the Jerseyan drift remains to be determined. Its degree of erosion and weathering seems to be about the same as that experienced by the Kansan drift and less than that displayed by the Jerseyan. The glaciation that laid down this drift probably covered the Cleveland district, but its drift in this area is buried beneath that of later glacial stages, the Illinoian and Wisconsin, which are well displayed here. This ice invasion seems to have crossed the Erie Basin from north to south, whereas the Illinoian and Wisconsin invasions each had an axial movement lengthwise of the Erie Basin. It was probably this glaciation that brought in copper ores from the Lake Superior Basin, now found in the drift of central and northern Ohio. There may be remnants of the resulting drift in the Cleveland district below the level of the streams and in the Erie Basin.

The data afforded by borings along the Cuyahoga Valley throw very little light on the question of the presence of pre-Illinoian drift. In none of the deep borings has a buried soil been reported. The drillers report the occurrence at various depths of a blue puttylike clay, gumming badly on bits, which is interbedded with more stony clay. The thickness of the soft clay beds is 25 to 30 feet or more, and there are two or three such beds in some of the wells. These beds appear to be ponded-water deposits rather than alluvial material, and they can scarcely be cited as evidence of interglacial stream work. The excavations for the Cleveland waterworks tunnel were reported by Newberry to have been in a pebbly blue clay that contained striated rocks and thus differed from the nearly pebbleless clay exposed in the ravines in the southern part of the city and in places along the lake shore. These excavations were carried in places to a depth of more than 100 feet below Lake Erie and reached the bedrock. They may therefore have passed through the oldest drift. A boring made by the Standard Oil Co. at the mouth of Kingsbury Run, in Cleveland, was reported by Newberry to have struck rock at a level of 228 feet below the surface of Lake Erie. In a depth of 238 feet the drill section shows 222 feet of blue clay and 16½ feet of sand and gravel in eight separate beds, each only a few inches thick. The great preponderance of clay characterizes nearly all the borings in the Cuyahoga Valley. Some of the borings, as indicated in the discussion of the bedrock surface (pp. 21–24), penetrated nearly to sea level before striking rock.

The exposed part of the pre-Illinoian drift in northwestern Pennsylvania[4a] varies greatly in constitution, being governed largely by the

[4a] Further study of the pre-Wisconsin drift in northwestern Pennsylvania since the above was written has led Mr. Leverett to regard it as of Illinoian age.—W. C. Alden.

nature of the drainage near the ice border. Where the ice caused a ponding of water in valleys that drained toward it a clayey drift was laid down, but where the water was free to escape from melting ice the drift is loose textured because of partial removal of the fine material. In the Cleveland district there was probably a general ponding of water along the ice border, as all the streams drained toward the ice, so that clayey drift is to be expected. What little sand and gravel are present seem likely to be referable to the action of water under hydrostatic pressure within the ice sheet rather than to free drainage outside.

As the ice movement that brought in copper ores appears to have crossed the Erie Basin in a north-south direction, it may have produced the north-south striae in northern Ohio and on islands in the western part of the Erie Basin noted by Newberry, Gilbert, and Winchell, as reported by Newberry,[5] who says that the glacial marks that have a nearly north-south trend are nearly obliterated by the stronger, fresher, and more numerous grooves whose bearing is nearly east-west.

### ILLINOIAN DRIFT

The Illinoian ice sheet is the earlier of the two that moved westward through the Erie Basin and spread southward into Ohio. In the eastern part of Ohio its southern limit is nearly coincident with that of the latest or Wisconsin glaciation, but in central and western Ohio (pl. 18) it extended farther south than the Wisconsin ice. The Illinoian drift is exposed in a narrow strip outside the later drift from a point near Mansfield southward along the west edge of the Muskingum drainage basin to Ross County and thence southwestward to the Ohio River in Adams County. It nowhere extends far beyond the Ohio River. It reaches about 10 miles beyond the river opposite Cincinnati and about the same distance near Bedford, Ky.

In the Cleveland district the Illinoian drift is exposed along the shore of Lake Erie east of the Cuyahoga River at many points, and it is slightly exposed where the old Rocky River came into the lake west of its present mouth. Exposures where recent excavations had been made north of Collinwood, examined by the writer in 1920, show a very hard blue till thickly set with small pebbles and traversed by joints and deeply weathered seams that are oxidized to a deep-brown color. This till is about as solid as frozen earth, and its removal by the pounding of the waves of Lake Erie is about as slow as that of the shale formations along the shore west of the Cuyahoga. In places the entire lake bluff is composed of fresh and easily excavated till, referable to the latest, or Wisconsin glaciation. In places there are overlying lake deposits. This part of the shore, therefore, affords interesting sections for study and comparison of both drifts.

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[5] Newberry, J. S., Geology of Ohio, vol. 2, p. 10, 1874.

The Illinoian drift probably forms a considerable part of the filling in the ancient Cuyahoga and Rocky River valleys, but like the pre-Illinoian drift it has not been fully separated from overlying drift of later age.

### POST-ILLINOIAN LOESS

Where the Illinoian drift is exposed outside the limits of the Wisconsin drift in Ohio it is covered by a thin deposit of silt loam known as loess, which was laid down by the wind. That this loess deposit is much younger than the Illinoian drift is known from the fact that the surface of that drift had become greatly eroded and weathered before the loess was laid down. The loess is of pre-Wisconsin age, for it occurs beneath the Wisconsin drift in southwestern Ohio. The loess may have extended over northern Ohio, but no exposures have been noted within the Cleveland district. Its thickness in central Ohio is usually less than 10 feet. It is dark brown and seems to have been completely leached of its calcareous material. Molluscan remains have been noted in buried portions of the loess under Wisconsin drift in southwestern Ohio, but none have been observed in the part outside the Wisconsin drift, perhaps because they have been leached out.

### LATEST OR WISCONSIN DRIFT

*General features.*—In the latest or Wisconsin glaciation the limit of the ice in eastern Ohio was between 60 and 75 miles south of the shore of Lake Erie (pl. 18), which was beyond the divide between the Erie drainage and the drainage to the Ohio River. The water from the melting ice therefore had free discharge southward along various lines to the Ohio. The valleys of these streams are filled for long distances with sand and gravel that consist of the same rock materials as are found in the glacial deposits and that are very different from the formations bordering the streams.

The edge of the drift has a general east-west course from the Pennsylvania line to the vicinity of Mansfield, Ohio. It there turns abruptly southward (pl. 18) because of an extension of the ice into the Scioto Basin and runs along on or near the divide between the Scioto and Muskingum Rivers to Ross County, keeping a few miles farther west than the edge of the Illinoian drift in this interval. From Ross County its general course is westward through the southern part of western Ohio. It comes within 12 miles of the Ohio River near Cincinnati, and it passes into Indiana directly west of Hamilton.

When the ice sheet had its greatest extension it was so thick that the underlying basins and ridges were wholly concealed by it, but as it became reduced in thickness from melting, the ridges and highlands became uncovered. As a result the edge of the ice took on a lobelike form. One of the lobes occupied the Grand River Basin in eastern Ohio (pl. 18 and fig. 8), and the ice spread from this basin toward the highlands on the east, south, and west. At that time the Cleveland district was being overridden by ice that was moving in a direction east of south toward the same highlands over which the Grand River lobe was spreading on its west border. There was a coalescence of this ice with that of the Grand River lobe for a few miles south of the shore of Lake Erie, but a great reentrant angle between the two masses of ice soon developed on these highlands. The water from the melting of the ice then issued into this angle and found a southward egress through the lowest places among the ridges and hills into the drainage channels that led to the Ohio River. The ice border stood so long on certain lines that morainic belts developed. These belts indicate how the ice border became changed from its general east-west course to the much more sinuous course around the basins and over the intervening highlands.

At a certain stage in its retreat the ice that moved across the Cleveland area came to have its border on the present divide between the St. Lawrence and Mississippi Basins, at the site of the city of Akron. At that time there issued from it a great volume of water, which flowed southward across this divide into the drainage tributary to the Muskingum River near Massillon. Its course is marked by a well-defined river channel, which is not now occupied by a stream. The head of this channel at Akron is about 390 feet above the level of Lake Erie, or 963 feet above sea level. Moraines showing the position of the ice border at that time extend into Akron from the east and west and pass the head of this channel.

Up to this time the water from the melting ice had an outlet to the south, and the moraines are made up largely of loose-textured drift, from which a considerable part of the fine detritus that had been contained in the ice was carried by the outflowing streams. When the ice border had retreated to a position within the present Lake Erie drainage basin, the water could not escape freely but became ponded, especially in the Cuyahoga Valley, and the ponding reached a sufficient height to give an outflow across the divide. Under these conditions the fine material contained in the melting ice was not carried away but was deposited where the ice melted. As a result the glacial deposits let down on this slope of the Erie drainage basin are very largely of a clayey character, though in places sand and gravel are found underneath a surface deposit of clayey drift. The moraines that were developed where the ice front halted in the course of its retreat are very weak and in places are difficult to trace. Parts of their lines, however, are sufficiently well defined to show the sinuosity of the ice border, with recesses on the uplands on each side of the Cuyahoga Valley and a great protrusion of ice into the valley.

The part of the Cleveland district that was uncovered earliest seems to lie in Richfield Township, Summit County, and neighboring parts of Hinckley Township, Medina County, and Royalton and Brecksville Townships, Cuyahoga County. It is a very high area, much of it between 1,200 and 1,300 feet above sea level. At about the same time a narrow strip of upland along the east border of the Cleveland quadrangle became free from ice.

The first-named area is limited on the east, north, and west by the Defiance moraine, there having been a great recess in the ice border here when that moraine was forming. The second area lies east of the moraine in a recess east of the Cuyahoga Valley. There are a few places in the southern part of the Cleveland quadrangle, outside the Defiance moraine, where the drift surface is somewhat more undulating than the ordinary ground moraine—for example, immediately west of Furnace Run along the south edge of the Cleveland quadrangle and around the corner of Medina and Summit Counties. There is also a group of knolls south of the county line 1½ miles west of this corner. Between these knolly spots the surface is generally smooth, like the ordinary ground moraine. There is a strip of knolly drift in northeastern Richfield Township about 2 miles long and a quarter of a mile wide, formed by a lobe of ice that lay in the Cuyahoga Valley. It stands about 100 to 150 feet higher than the border of the neighboring part of the Defiance moraine, which runs parallel to it less than a mile to the east. No continuation was found west of the Brecksville road. A well on this strip just east of that road and others midway of its length have reached depths of 50 feet or more without striking bedrock. Although it is not definitely connected with the knolly spots above noted, this strip is like them in being older than the Defiance moraine.

Aside from the places where the drift is aggregated in knolls, it is generally but a few feet to bedrock in the part of the Cleveland quadrangle outside the Defiance moraine. The drift is generally a clayey till of fresh appearance. On the east side of the Brecksville road north of Furnace Run is an exposure of rusty gravel which may be of pre-Wisconsin age, but no other exposures of old-looking drift were seen.

*Defiance moraine.*—The Defiance moraine, named from the city of Defiance, in northwestern Ohio (fig. 8), enters the Cleveland quadrangle from the east a short distance south of the northeast corner. It is here separated into two distinct strips of knolly drift, between which is a narrow smooth strip. The two knolly strips become united about 1½ miles north of Randall. The moraine passes over a prominent sandstone ridge, 1,200 to 1,240 feet above sea level, in the northeastern part of the Cleveland quadrangle. On the west slope of this ridge the moraine, in a short distance, drops below the 1,100-foot contour. For about 4 miles north of Bedford the moraine controls the course of a northern tributary of Tinkers Creek, which follows the outer border of the moraine southward. On crossing Tinkers Creek, south of Bedford, the moraine follows its south bluff southwestward for 2 miles and then takes a southward course past Northfield to the limits of the Cleveland quadrangle. The south end of the morainic loop is only a mile farther south, at Peninsula. The moraine there crosses to the west side of the Cuyahoga River and doubles back to the north, into the Cleveland quadrangle. It crosses from Summit into Cuyahoga County near the northeast corner of Richfield Township, takes a northwest course to Chippewa Creek at Brecksville, and follows the south side of that creek to the west line of Brecksville Township. The moraine is ill-defined for about 2 miles west of this line but becomes more definite near the headwaters of Chippewa Creek, about 1½ miles southwest of Walling Corners, and follows the general course of the road that leads from Walling Corners to North Royalton, being nearly on the brow of the Pottsville escarpment. It turns southward near North Royalton, and for 3 miles determines the southward course of the East Branch of the Rocky River, which follows its outer edge. In Hinckley Township this branch of the Rocky River turns to the north, and the moraine crosses its valley near Hinckley village, about a mile south of the south edge of the Cleveland quadrangle. Its course is thence westward through the southern part of the Berea quadrangle for about 6 miles before it passes into the Medina quadrangle. The main part of the moraine lies south of Big Brook, in Hinckley Township, but in the vicinity of Bennetts Corners there is an inner ridge along the north side of Big Brook, which is traceable from the area near the head of the brook eastward for 2 miles.

The course of the Defiance moraine is controlled very largely in the Cleveland district by the topographic conditions, there being a great protrusion southward into the Cuyahoga Valley, forming a lobe about 8 miles long, which tapers from a width of 6 miles at the north to about 3 miles at the south end. The uplands on each side of the Cuyahoga Valley cause pronounced reentrants in its course. The moraine is about 950 feet above sea level at the end of the lobe in the Cuyahoga Valley and rises northward on each side of the valley to more than 1,200 feet at the reentrant angles. On the east side it reaches an altitude of fully 1,240 feet, and on the west side, north of North Royalton, the measured altitude of one point on it is 1,265 feet. On the high land west of the East Branch of the Rocky River, in the southeastern part of the Berea quadrangle, it is slightly less than 1,200 feet, although in northern Brunswick Township the moraine passes south of a ridge of Sharon conglomerate which is 1,220 feet high. It is only about 900 feet above sea level in the valley of the East Branch of the Rocky River near Hinckley village.

The thickness of the drift in this moraine is somewhat greater than on the level tracts on each side, the difference corresponding nearly to the relief of the moraine, which is 20 to 30 feet above the bordering tracts. The drift varies in thickness also to correspond with the relation of the moraine to preglacial valleys and ridges. On the preglacial ridges the thickness of drift is generally not less than 30 feet, but on the bordering level tracts it may be less than 10 feet. Where the moraine crosses valleys the thickness is usually very great, because the preglacial streams had cut to a much lower level than the present drainage lines, whose grade is adjusted to the level of Lake Erie. As indicated elsewhere the rock bed of the preglacial Cuyahoga is about down to sea level in the north half of the Cleveland quadrangle and is below the level of Lake Erie through its entire course across the quadrangle. There is probably at least 500 feet of drift at the place where the Defiance moraine crosses the preglacial Cuyahoga near Peninsula. At the south line of Cuyahoga County borings in the preglacial Cuyahoga channel have shown the rock floor to be about 175 feet below the level of Lake Erie, or 400 feet above sea level, whereas the Defiance moraine which borders this portion of the valley, is 950 to 1,000 feet above sea level.

The till in the moraine is shown by well borings to be oxidized to yellowish brown to a depth of 10 to 15 feet or more, below which it is blue or gray. Near the south end of the morainic loop, in Boston Township, and in the southern part of Northfield Township the till along the course of the moraine is in places underlain at a depth of 25 to 30 feet by a nearly pebbleless blue clay. There are good exposures of this clay where Brandywine Creek passes through the moraine, near the line between Boston and Northfield Townships, and on streams farther south. The upper part of this clay appears fresh and seems to have been laid down in ponded waters just before the ice made a readvance to the position marked by the Defiance moraine. It should not, however, be inferred that all the silt in the Cuyahoga Valley was laid down at this time. In the deep gullies leading into the Cuyahoga east of Boston, exposures of a much indurated brown silt are found below this fresh blue silt.

*Ground moraine or till plain north of the Defiance moraine.*—A till plain occupies the part of the Berea, Cleveland, and Euclid quadrangles between the Defiance moraine and the shore line of glacial Lake Maumee, except in the eastern part of the Euclid quadrangle, where the Euclid moraine is present, and at a morainic strip in Brooklyn Township. This plain occupies fully two-thirds of the area of the Berea quadrangle, about half the area of the Cleveland quadrangle, and one-third the area of the Euclid quadrangle. Its surface is remarkably smooth, there being very few drift knolls on it that are as much as 10 feet high, and not many that reach 5 feet. It rests, however, on a surface that slopes steeply toward the Cuyahoga Valley and toward Lake Erie. By reference to the contour maps it will be seen that a difference in altitude of 100 feet in a mile is not uncommon. In the Berea quadrangle, however, southwest of the village of Berea, there is a wide area of till plain in which the slope is very gentle from south to north, in places less than 10 feet to the mile. A strip of similar slope stretches from Berea northeastward into Brooklyn Township, crossing Middleburg and West Park Townships. This part with the gentle slope is on the Erie Plain, and the other with steeper slope is on the border of the Appalachian Plateaus. In both situations the sheet of till is very thin, except where old valleys are crossed, rock being usually found at depths of less than 20 feet. The drift is very clayey, with few if any deposits of sand or gravel on its surface.

Where valleys have been filled deposits of gravel of considerable depth are found in places under a thin coating of clayey till. Such deposits along Mill Creek east of the insane asylum have been opened extensively for sand and gravel. The excavations are in places 60 feet deep. These deposits show remarkable variation in coarseness, ranging from cobble beds to fine sand. The bedding is very discordant, some beds having been partly washed away and a filling of material of different texture brought in. As there is enough lime in the deposits to cement them to some extent, the walls of many pits present nearly vertical faces, even where they consist of fine sandy material. A view in one of these pits north of Mill Creek and west of Henry Road is shown in Plate 17, *A*.

Beds of sand and gravel of this sort appear to have been laid down underneath rather than outside the ice, in places where there was sufficient hydrostatic pressure to produce strong currents, with enough difference in strength to determine the many differences that the deposits exhibit. The bedding is not so regular as in outwash deposits laid down beyond the limits of the ice. Furthermore, it is unlikely that there was free drainage outside the ice at the level of these deposits. They are considerably lower than the southward-draining channel at Akron, being about 840 to 900 feet above sea level, whereas the bed of the channel at Akron is above 960 feet. It is also unlikely that there was at this time a westward line of escape, for in order to form such a feature the ice border must have been below the Berea escarpment west of the Cuyahoga and must have uncovered the entire lower course of Mill Creek. The sand and gravel deposits were probably laid down while the limit of the ice was at or near the Defiance moraine, and the clayey till that covers them was probably deposited while the ice was melting back from the moraine toward the basin of Lake Erie.

*Euclid moraine.*—The Euclid moraine comes into the eastern part of the Euclid quadrangle as far as Euclid village, along the north side of an eastern tributary of Euclid Creek. The morainic features do not continue beyond Euclid, but the ice border probably extended southwestward into Cleveland along the edge of a shale escarpment that formed the limit of subsequent glacial-lake action. The waters of the glacial lake may have removed any morainic deposits laid down along the face of the escarpment.

Within the Euclid quadrangle the Euclid moraine is only half to three-quarters of a mile wide, and the drift on it is only a few feet thick. The surface, however, has the swell and sag morainic topography, and the moraine becomes much stronger to the east, in the Mentor quadrangle. It is composed of very clayey till. There probably was some ponding of water on its outer border when it was being laid down.

*Moraine in Brooklyn Township.*—A weak moraine runs across the southern part of Brooklyn Township from the Cuyahoga Valley to the west edge of the Cleveland quadrangle, in a course slightly north of west. A tributary of Big Creek is held to a westward course for about 3 miles by the moraine, and another small stream leads in the opposite direction to the Cuyahoga, on the outer side of the moraine. The moraine is about half a mile wide where best developed and stands about 20 feet above the edge of the plain on the south. It has a swell and sag topography of mild expression. The drift is of moderate thickness and composed of clayey till. This moraine may be correlative with the Euclid moraine, although this correlation is different from an earlier one made by the present writer.[6] Its altitude is very nearly the same as that of the west end of the Euclid moraine, the highest points being about 800 feet above sea level. It is slightly higher than the brow of the shale bluff in the eastern part of Cleveland, which seems not to have been surmounted by the ice when the Euclid moraine was being formed. Although it seems strange that this bluff was not surmounted if the ice was up to this moraine in Brooklyn Township, the conditions are about the same as are shown by the Defiance moraine in the Cleveland quadrangle. That moraine reaches fully as high an altitude near North Royalton, in the southwestern part of the quadrangle, as it does in the northeastern part, and it is at a decidedly lower altitude in the intervening part near the Cuyahoga Valley.

The course of Mill Creek below the falls in the southeastern part of Cleveland may have been determined by the border of the ice at about the time the Euclid moraine was being formed. It turns abruptly southward instead of continuing directly westward into the Cuyahoga River. The ridge on the west side of Mill Creek is a gravelly bar formed by glacial Lake Maumee, but there is a heavy deposit of till beneath it, and this may partly bridge the gap between the Euclid moraine and the moraine in Brooklyn Township.

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[6] Leverett, Frank, Glacial formations and drainage features of the Erie and Ohio Basins: U. S. Geol. Survey Mon. 41, p. 619, pls. 13 and 15, 1902.

As to the continuation of the ice border from the west end of the moraine in Brooklyn Township, the evidence is not clear. For 3 miles westward the drift is very thin and the rock surface is higher than in the district immediately south. The area to the south is flat as well as low and shows no indication of a continuation of the moraine. On the west, near Kamms, there is a gently undulating drift surface, and a strip of land along the highway from Kamms to Berea stands slightly higher than the land on the east, drained by a tributary of Big Creek, and the drift is much thicker than it is east of Kamms. It requires close scrutiny and the aid of the topographic map to discover that there is a ridge along this highway, or that it has any more undulation than the plain on the east. It is therefore merely suggested as a possible course of the ice border. West of Berea, along and near the New York Central Railroad (Lake Shore & Michigan Southern line), the surface seems to be slightly more undulating than it is on the south. But here, as in the district between Kamms and Berea, there is merely a suggestion of the course of the ice border and not clear and satisfactory evidence.

### THE GLACIAL LAKES

*General features.*—As the ice melted out of the Maumee and Erie Basins in northern Ohio and neighboring parts of Indiana, Michigan, and Ontario, ponding of water began with a small lake at the extreme west end of the Maumee drainage basin and other small lakes in the southern tributaries of Lake Erie, including one in the Cuyahoga Valley. As the melting of the ice continued, these small lakes were drawn down to the level of a large lake known as glacial Lake Maumee (pl. 11), which at first discharged into the Wabash Valley past Fort Wayne, Ind., and later across the Thumb of Michigan into the Grand River Valley and thence into the Lake Michigan Basin. The ice covered the Cleveland district while the lake discharged past Fort Wayne, but by the time that the outlet across the Thumb of Michigan was opened, the ice had disappeared from this district. A lake then extended from northeastern Ohio westward into Indiana and northward to the southeastern part of Michigan, as well as over the present area of Lake Erie. Its altitude was 760 to 765 feet above sea level, or 190 feet above the present level of Lake Erie. Its outlet on the Thumb of Michigan was controlled by the position of the ice border and was the lowest available place outside the edge of the ice. The lake appears to have discharged by this outlet for a considerable time, for the rivers that came into the lake formed good-sized deltas at its level.

The ice then readvanced and moved southward upon the Thumb of Michigan, blocking this outlet and causing the lake to rise to the level of a slightly higher passage across the Thumb, which it utilized as a line of discharge. The effect of this advance of the ice was manifested all around the shore of the lake, for the lake deposits of this later stage reach an altitude about 20 feet higher than those of the preceding stage. The Cleveland area is an excellent place for studying the evidence of this rise of the lake, for it shows the strong wave effects at about 760 feet above sea level, with definite banks rising about 20 feet higher. When the rise of water occurred the slopes of these banks became coated with beach material, and the waves built beaches at the top of the bluff or cut notches near the level of the top to correspond with the new altitude that the lake had assumed. The outer beach, therefore, in much of its course across the Berea and Cleveland quadrangles, is the product of two lake stages, the steep bluff being formed by the lower and earlier stage and the gravel coating along or on it by the later one.

Later fluctuations of the ice border on the Thumb of Michigan brought the lake at first down to about 710 feet above sea level and then raised it to about 735 feet. The Cleveland area furnishes clear illustrations of this fluctuation of lake level, for the beach at 735 feet is along the top of a bluff that had previously been cut down to about 710 feet.

The lake levels were next affected by the melting away of the ice in western New York, which opened a passage near Syracuse into the Mohawk Valley, and the lake was drawn down from 735 feet to 660 feet. Then the ice readvanced in western New York and crossed this outlet, causing the water to return to the western outlet through the Grand River, in Michigan, at an altitude of 680 feet. The Cleveland area also shows definite evidence of this fluctuation of the lake, for the shore line at 680 feet is along the bluff that had previously been cut to about 660 feet. During this lake stage the outlet through the Grand River was lowered to 670 feet or slightly less. In the Cleveland area the Woodland Avenue beach marks the level of the lake when it stood at 680 feet, and the Euclid Avenue beach marks the altitude when it had been lowered to 670 feet.

The ice in New York then melted back and again opened an outlet into the Mohawk Valley, which was about 640 feet above sea level and a little later was reduced to 620 feet. There are weak shore lines in the Cleveland district corresponding with each of these levels of the outlet. A little later the ice receded sufficiently to drain the Erie Basin to the level of the present outlet at Buffalo and to initiate the Niagara Falls at Lewiston.

*Glacial Lake Cuyahoga.*—The name Lake Cuyahoga was applied by Claypole [7] to the ponded waters held between the retreating ice border and the divide at Akron that separates the Lake Erie from the Ohio River drainage. The lake deposition was thought to be restricted

[7] Claypole, E. W., "Lake Cuyahoga"; a study in glacial geology [abstract]: Am. Assoc. Adv. Sci. Proc., vol. 36, p. 218, 1888.

to the material laid down in these ponded waters during the final recession of the ice border in the Wisconsin stage of glaciation. The conditions were evidently much more complex than Claypole set forth, however, and ponding of this sort appears to have occurred several times. In each of the glacial invasions the Cuyahoga River was probably ponded in front of the advancing ice until the ice had reached the divide. At the time of the earliest invasion the divide was probably much farther south than Akron, and it may also have been farther south in the Illinoian stage. It did not become located at Akron until near the end of the Wisconsin stage. As a result of this ponding during and after each glaciation, together with the deposition of glacial material, the valley filling is very complex.

The final ponding of the Cuyahoga appears to have been of very moderate length and the amount of deposition in the valley rather slight. So far as known to the writer this final stage is not marked by definite shore features but is more clearly shown in the outlet channel that leads through Akron, the head of which is about 390 feet above Lake Erie and 963 feet above sea level. This channel, however, served as a glacial drainage line before it became the outlet of Lake Cuyahoga.

Each of the branches of the Rocky River probably held a similar lake. The one on the West Branch apparently discharged to the River Styx at an altitude slightly above 1,000 feet, and the one on the East Branch reached 1,060 feet, at the present head of that stream, and discharged into the headwaters of Yellow Creek, a tributary of the Cuyahoga.

*Maumee beaches.*—The Maumee beaches within the Cleveland district have their best development in the Berea quadrangle. They are much interrupted in the Cuyahoga and Euclid quadrangles. At the west edge of the Berea quadrangle, near Fields, stand two ridges, locally known as Butternut Ridge and Chestnut Ridge. Butternut Ridge is a complex shore line in which each of the two beaches is represented. Chestnut Ridge is an offshore bar of the lower Maumee beach. The portion of the outer shore between Fields and the place where the Cleveland Southwestern Railway & Light Co.'s electric line comes to it is notably prominent, with a relief on its northwest side of 20 to 25 feet. The base of this bluff marks the level of the lowest stage of glacial Lake Maumee, 760 feet above sea level, and the bluff seems to have been cut while the lake was at this low stage. On top of the bluff is a gravelly deposit at 775 to 780 feet, which was formed when the lake rose to the higher level as a result of the advance of the ice on the Thumb of Michigan.

While Lake Maumee was cutting this bluff the offshore bar, Chestnut Ridge, was formed about a quarter of a mile out in the lake. This bar is composed mainly of fine sandy gravel, but when the lake rose to the higher level a finer sediment was laid down upon it, so the ridge has now a loamy soil. It is thus in striking contrast to the higher beach, Butternut Ridge, the gravel of which has very little clay or loam admixture.

A little farther east the Maumee beaches take on unusual complexity. The lower Maumee beach follows the base of the lake bluff to North Olmsted and seems to have continued eastward to the Rocky River bluff along the 760-foot contour. Later it developed a strong bar, which is followed by the electric railroad from North Olmsted to the Rocky River. It is not a simple bar but has hooks, forks, and other complexities. It seems to have been a long time in forming and to have been built from the west end, near North Olmsted, eastward until it had reached a length of 5 miles. Back of it was very shallow water, extending to and beyond the valley of the Rocky River.

There is a conspicuous gravel bar a mile east of Dover, which probably was formed while Lake Maumee was at this low level. It is entirely isolated from the shore south of it, and was apparently built up on a shallow place in the lake. Its altitude is between 750 and 760 feet, and it stands 8 to 12 feet above the bordering clay plain. A gravel pit on a high part of the bar shows the deposit of gravel to be about 12 feet thick. This bar has hooks running eastward from each end, showing that it was built by waves rolling in from the west.

East of the Rocky River, along the Warren Road, from a point near the line of Rockport and West Park Townships southward, stand clay ridges which correspond in altitude with the low level of Lake Maumee and have about the breadth and height of a shore line but in which there appears to be no sand or gravel. They are in a district in which clay shale is close to the surface, and possibly there was no other material for the waves of Lake Maumee to work upon to form a beach deposit. They are not distinguished on the map from the lake-bed clays.

The higher shore of Lake Maumee is marked by great complexity from North Olmsted eastward, there being several strong bars that radiate toward the valley of the Rocky River. The southernmost of these bars is far outside the others and has a lower altitude, for it does not quite reach the 770-foot level. It lies along a road that branches from the road leading south from North Olmsted and runs southeastward to the bluff of the West Branch of the Rocky River a mile north of Olmsted Falls. The low altitude of this bar may perhaps be due to its having been formed while Lake Maumee was rising from the 760-foot to the 780-foot level. That it was submerged after its sand and gravel had been deposited is indicated by the presence of a thin coating of loam. The depth of submergence was only 10 to 12 feet.

The main work of the higher lake stage in the vicinity of North Olmsted consisted in the development of a strong gravel bar for about

2 miles southwest of that village and a series of radiating bars extending eastward from the village. The outer radiating bar is only a mile long and dies out before reaching the bluff of the Rocky River. Two others are strongly developed clear to the river bluff near Olmsted, a distance of about 2 miles. The southern one was formed first. The amount of work done here at this higher stage seems to demand a considerable duration of time.

On the east side of the Rocky River a strong gravel bar sets in directly east of Abram Creek and runs along the road northeastward for about 2 miles, to a place where another eastern tributary of the Rocky River comes in. This bar is in places fully one-eighth of a mile wide, and the gravel is several feet deep. It seems to have been developed entirely at the higher lake stage, its altitude being about 780 feet above sea level.

North of this small eastern tributary another large gravel bar appears and runs northeastward about 1½ miles. Large pits have been opened in this bar to obtain gravel for roads. Its altitude is that of the higher stage of Lake Maumee, and it seems to have been entirely developed at that stage. There are other gravel bars along the east bluff of the Rocky River near Kamms, developed at the same stage.

From Kamms eastward the electric railroad runs for about 1½ miles along a gravelly bar built at the higher stage of Lake Maumee. Outside of this bar, setting in at the New York Central Railroad and running northeastward, is another gravel bar, which terminates at the bluff of a small western tributary of Big Creek, a short distance north of Lorain Avenue.

The gravel bars just mentioned are on the prominent shale area north of a western tributary of Big Creek. There was a submerged area south of them, but the water was too shallow for effective wave action, so the limits of the lake south of this submerged area must be arbitrarily placed along or near the 780-foot contour. The waters of Lake Maumee at the lower lake stage seem to have had their limit on the northern slope of this prominent shale area. A gravel bar is developed along part of this slope from the New York Central Railroad eastward, but the shore is mainly a lake cliff west of the railroad.

Near Lorain Avenue the gravel bar becomes split up. An outer bar runs directly south to North Linndale and is paralleled by another bar a short distance to the east. The main bar runs southeastward and crosses the Big Four Railroad near the east edge of the Berea quadrangle. The main bar appears to have been begun at the lower lake stage but was built up to a higher level during the succeeding higher lake stage. The bar continues into the Cleveland quadrangle about a mile and terminates at the north bluff of Big Creek.

South of Big Creek Lake Maumee at the lower stage made a definite lake cliff on the north slope of the moraine in Brooklyn Township for

3 miles westward from Brooklyn, or to the line between the Cleveland and Berea quadrangles. When the lake rose to the higher stage a gravel deposit was spread in places on the slope of the moraine up to a level about 20 feet above the foot of the bluff that had been cut at the lower stage. The gravel coating is usually not more than 2 to 5 feet thick and forms a veneer on the clayey till of the moraine. The moraine becomes so low a short distance east of Brooklyn that the lower Maumee beach is found along its crest. This beach extends only a short distance into Independence Township, where the moraine drops too low to catch it.

The beach sets in on the east side of the Cuyahoga Valley, on Warner Road east of Mill Creek. A bar and hook curve around to the east at its south end. This bar appears to have been built during the higher stage of Lake Maumee, for its altitude is a few feet above the level of the lower lake stage. The shore line of Lake Maumee runs along the east side of Mill Creek from its mouth northward to the falls near the crossing of the Pennsylvania Railroad. On the west side of the creek for about a mile below the falls there is a gravel bar at the height of the lower Lake Maumee shore.

Northward from the falls of Mill Creek the Maumee shores at both lower and higher stages are ill defined or are represented by a steep shale bluff. There is a slight deposit of gravelly material around which Giddings Brook makes a bend as it passes below the 780-foot level. This deposit is traceable for about half a mile southward along the brow of a shale bluff, the base of which seems to have been washed at the lower lake stage. The bluff directly back of Fairmount Reservoir may have been steepened somewhat by the action of Lake Maumee. In the Euclid quadrangle no other features than the steep shale bluff were recognized that seem referable to Lake Maumee. The effect of the lake may have been merely to increase the steepness of this bluff and not to have determined its presence. As a feature of relief it probably antedated the glacial epoch.

*Work of Cuyahoga River at time of glacial Lake Maumee.*—While Lake Maumee was developing its shore lines the Cuyahoga River graded its channel to a corresponding altitude, and along its border remnants of the stream bed of Maumee time can still be traced. One of the best-preserved remnants lies back of Brecksville station, where an area of more than half a square mile is covered with river rubble. There is a continuous coating with pebbles and cobblestones, the largest 6 inches or more in diameter, extending from 760 feet up to about 790 feet above sea level. There is no terracing of the slope between 790 and 760 feet, which is thought to indicate that the deposit of river rubble was built up with the rise of the lake level. If so the rubble at about 790 feet was laid down later than that lower on the slope. This veneering with rubble ends just east of the forks of the road midway between Brecksville village and the railroad station. For nearly a quarter of a mile farther west and up to an altitude 10 to 15 feet higher the slope is coated with a clay deposit, which may have been laid down at flood stages. The river rubble seems to represent work along the bed of the stream and not the full upper limit of the water. Remnants of the valley filling of the Cuyahoga on each side of the mouth of Tinkers Creek have about as great extent as those near Brecksville station and are of similar character. There are smaller remnants scattered along the valley down about to the place where the Maumee beaches cross the valley. The northernmost place noted is on the east side of the Cuyahoga about a mile south of the mouth of Mill Creek, where a spur projects into the valley. This spur drops below the level of Lake Maumee, but the part above 760 feet is coated with coarse river rubble, some stones being a foot in diameter. This deposit is exposed along the Pittsburgh & Lake Erie Railroad (not shown on the map) for about a quarter of a mile farther north and is from 2 to 6 feet deep.

*Work of Rocky River at time of glacial Lake Maumee.*—When Lake Maumee was at its lowest level the Rocky River entered the lake immediately north of Olmsted. For 3 miles farther down the river there is on the left or northwest bank a deposit of sandy gravel similar to a natural levee which may have been brought in by the river to fill a lagoon south of the Maumee bar along which the electric railroad runs from North Olmsted eastward. It is probable that this deposit was not extended down the valley until the bar had been developed as far down as the vicinity of the line of Dover and Rockport Townships, for up to that time the lake waves were free to extend clear to the river. When the bar had been developed, the shallow waters of the lagoon were entered by the strong current of the stream, and the stream then extended its deposits into the lagoon and thus built the supposed natural levee. In doing so it reworked some of the material that had been developed by the lake, so that this strip of sandy gravel is a combination of lake and stream work.

When the lake rose to the higher level the water covered this part of the Rocky River Valley and extended up both branches of the river to 775 or 780 feet above sea level. On the East Branch its limit was at Berea; on the West Branch it was as far up as Westview. The stream at this higher lake stage made no conspicuous deposits where it entered the lake, though a thin deposit of pebbly material is found on the till about half a mile above Westview on the west side of the West Branch. On the East Branch in Berea, near the falls by the railroad bridge, there is also more or less waterworn material, which was probably laid down by the river while the lake stood at its highest level.

All the other streams that entered Lake Maumee were very small, and their delta deposits have been largely removed by later streams.

*Lake bed between shore lines of glacial Lake Maumee and those of glacial Lake Whittlesey.*—In the Berea quadrangle the portion of the bed between the shore lines of Lake Maumee and those of Lake Whittlesey is composed almost entirely of stiff clay, which seems to have been formed partly from till and partly from the underlying shale which was cut into by the lake. There is some sandy loam in the part traversed by the preglacial Rocky River.

In the Cleveland and Euclid quadrangles the space between the Maumee and Whittlesey shore lines is very narrow, and from the eastern part of the Cleveland quadrangle northeastward it is occupied nearly everywhere by an outcrop of shale. On the border of the Cuyahoga Valley and eastward to the border of the uplands the space between the shore lines is filled in with clayey material instead of sand and gravel. The deposits of clay, sand, and gravel are indicated on the geologic map.

*Shore of glacial Lake Arkona.*—The next lake stage after the higher Lake Maumee is termed Lake Arkona, from a town in Ontario where it was first studied. This lake as a whole, because of a recession of the ice border to the northeast, covered a much larger area than Lake Maumee, though at a lower level, about 710 feet above sea level, but it was cut 15 feet lower during the life of Lake Arkona. In consequence of this lowering the Arkona beach is separated into two or three ridges differing slightly in altitude, the highest being at about 710 feet and the lowest a little below 700 feet. The lower beaches in the Erie Basin were to a great extent washed away when the water later rose to a higher level. Where they are of exceptionally coarse material they are best preserved. Elsewhere their positions are identifiable by the occurrence of more sandy and gravelly soil along the lines that they occupied than on the bordering areas. When the rising lake washed these ridges it removed the fine material and flattened them but did not scatter all the coarse material.

In the Cleveland district the waters of Lake Arkona probably did most of the cutting of the steep bluff along Middle Ridge, in the Berea quadrangle. The base of this ridge is near the 710-foot contour. The ridge has had a similar history to that of Butternut Ridge, the lake cliff having been cut by a low stage of water and the gravel deposits on the face and top laid down later by a higher stage of water, that of Lake Whittlesey. This bluff is conspicuous for its entire course across the Berea quadrangle and to the border of Big Creek Valley in the western part of the Cleveland quadrangle. The shore line of Lake Arkona crosses to the south side of Big Creek Valley at

Brookside Park. Thence it runs eastward to the Cuyahoga Valley about at the line between Brooklyn and Independence Townships. East of the Cuyahoga it extends to the foot of the slope below the Lake Whittlesey beach, from the Cuyahoga bluff northeastward past Burk Branch and Morgan Run and northward close to the 700-foot contour in the Cleveland and Euclid quadrangles.

*Work of Cuyahoga River at time of glacial Lake Arkona.*—The Cuyahoga River seems to have cut its valley down to about 700 feet in the vicinity of Willow at the time of Lake Arkona and to have deposited gravel beds, now exposed in pits west of the Brecksville Road and where the Schaaf Road rises from the Cuyahoga Valley west of Willow. These gravel deposits are covered in both places by a few feet of clay, which was probably laid down when the lake rose to the Lake Whittlesey level. On the east side of the Cuyahoga is a narrow strip of gravelly land that barely reaches the 700-foot contour. It lies along the Independence Road south of the end of the Whittlesey beach. All these deposits of gravel are close to the place where the Cuyahoga came into Lake Arkona and are better preserved than the few deposits made farther up the valley at a level correlative with Lake Arkona.

*Shore of glacial Lake Whittlesey.*—Lake Whittlesey, named in honor of Col. Charles Whittlesey,[8] a former resident of Cleveland, was the successor of Lake Arkona. There is a heavy bed of sandstone at the head of the outlet, near Ubly, Mich., which resisted erosion and thus held the lake at a constant level. This condition tended to produce a shore line of exceptional regularity and strength.

In the Cleveland area the Whittlesey shore line enters the Berea quadrangle from the west at the electric railroad. It is known as Middle Ridge and takes a northeastward course past Bement and Dover to Rockport, on the bank of the Rocky River. In places there are two or three parallel gravel ridges, as in the section southwest of Dover, but generally there is a single strong ridge. Where this beach is exceptionally strong it reaches an altitude of 740 feet, but it seems to mark a lake level at about 735 feet.

On the east side of the Rocky River there is a gravelly ridge for about a mile, but for the next 2 miles eastward, to the crossing of the New York Central Railroad, there is a lake cliff cut in the shale. There are scarcely any gravel deposits in this interval. From the New York Central Railroad crossing the beach bears southeastward and crosses Lorain Avenue at the west end of Dennison Avenue. It follows Dennison Avenue southeastward into the Cleveland quadrangle, a distance of about 2 miles. This part is a conspicuous gravel bar standing about 20 feet above the plains on each side. It ends at

[8] Taylor, F. B., Geol. Soc. America Bull., vol. 8, p. 39, 1897.

the north bluff of Big Creek, about 2 miles west of the Cuyahoga River.

The Whittlesey shore sets in on the south side of Big Creek in Brookside Park and runs southeastward through Brooklyn and along the north side of the Schaaf Road about to the line of Independence Township. It then follows the Schaaf Road to the place where the road descends to the Cuyahoga Valley at Willow, having in much of its course a conspicuous ridge of sandy gravel.

On the east side of the Cuyahoga River the Whittlesey shore is represented by two ridges, one of which follows closely the west bluff of Mill Creek for about a mile and then continues northward along the Brecksville Road into the city of Cleveland. The other ridge sets in at the Independence Road about a mile south of Harvard Avenue and takes a northeastward course, coming to Harvard Avenue where it touches the south bluff of Burk Branch. The space between these two ridges is a clayey plain nearly a mile wide at the southwest but narrowing to about a quarter of a mile at Burk Branch. On the north side of Burk Branch there is a single ridge between that stream and Morgan Run. Thence the beach takes a northward course and comes to Kingsbury Run near the place where the Pennsylvania Railroad crosses the stream. North of Kingsbury Run the Whittlesey beach runs along the base of a shale bluff in the northern part of the Cleveland quadrangle and throughout its course in the Euclid quadrangle, there being very few places in which gravelly or sandy deposits are present. There is a notch in the cliff, which with a terrace in front of it is thought to mark the amount of work done by the lake in excavating the shale. The contours on the map show that the space between the 720-foot and 740-foot contours is generally somewhat wider than that between the contours higher up on the face of the bluff. This difference in space is the measure of the width of the terrace formed by the encroachment of the lake on the bluff.

*Work of Cuyahoga River at the glacial Lake Whittlesey stage.*—Along the Cuyahoga Valley there are several conspicuous remnants of the river bed occupied during the time of Lake Whittlesey. A prominent flat-topped area that extends well out toward the river near Thornburg carries a deposit of river rubble. The highest part of it is 740 feet above sea level. Other remnants lie on each side of Tinkers Creek and from Brecksville station north for about 1½ miles. There appears to have been very little descent in the Cuyahoga from Brecksville station northward, so the deposits just mentioned are the result of the filling of a pool that extended up the river beyond the limits of the open lake. The valley had been cut down in Arkona time to a level so much lower than that of Lake Whittlesey that the rise of the water to the Whittlesey level naturally produced slack water some distance up the valley, probably as far as Brecksville station. Delta-like filling of a pool on a stream where it entered Lake Whittlesey is common, especially on the streams of southeastern Michigan.

Whatever deposits were laid down by the Rocky River at the time of Lake Whittlesey seem to have been largely removed by subsequent erosion, so the work of that stream during this time is not easy to point out. The same is true of the smaller tributaries of Lake Whittlesey in the Cleveland area.

*Lake bed between the Arkona-Whittlesey shore and the glacial Lake Warren shore.*—In the Berea quadrangle the space between the Arkona-Whittlesey and Warren shores is about 3 miles wide at the western edge but becomes narrowed to about a mile at Dover, and it holds about this width to the Rocky River. The soil in this area is a heavy clay from the west side of the Berea quadrangle eastward to a line within 2 miles of the Rocky River, and shale is found very close to the surface. In the 2 miles adjacent to the Rocky River, which was traversed by the preglacial river valley, the drift deposits are thick, and the soil is of much looser texture, ranging from sandy loam to finer material.

East of the Rocky River the space between the Arkona-Whittlesey and Lake Warren shore lines is less than half a mile wide in most places, and the soil is heavy clay, with shale at slight depth, as far east as the west edge of the Cleveland quadrangle. In the Cleveland quadrangle there is a much wider space between these shores than in the district on the west, its width being as much as 5 miles immediately east of the Cuyahoga River. This area was filled to a great depth with deposits of glacial and lake material. A considerable part of it has a clayey soil, and the underlying deposits are pebbleless clay to a considerable depth. This clay has been drawn upon extensively for the manufacture of brick and other clay products. In the Euclid quadrangle the Whittlesey and Warren shores lie very close together, with only a strip of nearly bare shale between them.

*Shore of glacial Lake Wayne.*—The altitude of glacial Lake Wayne where there has been no subsequent uplift of its shore lines was about 660 feet above sea level, or about 75 feet lower than its immediate predecessor, Lake Whittlesey.

In the Cleveland district the shore of Lake Wayne ran along the base of the beach that is followed by Detroit Road and Detroit Avenue across the Berea quadrangle and the part of the Cleveland quadrangle west of the Cuyahoga River. The lake cliff back of it rises abruptly to a height of about 20 feet and is largely cut in the shale. For 2 miles west of the Rocky River, however, it is cut in glacial deposits. It is also cut in glacial deposits from a point near the east edge of the Berea quadrangle eastward to the Cuyahoga River.

Immediately east of the Rocky River there is a somewhat distinct ridge of Warren shore that lies a short distance back from the top of the lake cliff cut by Lake Wayne, but elsewhere the Warren beach is near the brow of the cliff cut by the waters of Lake Wayne all the way from the west side of the Berea quadrangle to the Cuyahoga River.

East of the Cuyahoga River the Lake Wayne shore crosses a sandy and gravelly deposit and lies a short distance north of Euclid Avenue along or near the 660-foot contour. From it there is a rise to the shore of Lake Warren that is followed by Euclid Avenue through nearly the whole interval from the Cuyahoga River to Doan Brook.

Gravel and sand extend but a short distance east of Doan Brook, and shale sets in near Lakeview Cemetery and extends northeastward across the Euclid quadrangle. The shore is cut into shale except for a short space near Euclid Creek, where there is some stony drift material. Because it lies close to the beach of Lake Warren, this shore line is commonly referred to as the product of that lake, but probably Lake Wayne did the major part of the cutting of the lake cliff that was later washed by Lake Warren. What has been taken to be a single shore line is really a compound one; part of it was formed by a lake that discharged to the Atlantic Ocean and part of it by a lake that discharged to the Gulf of Mexico, yet the level of the two lakes differed only 20 feet.

*Work of Cuyahoga River at the time of glacial Lake Wayne.*—It is probable that a large part of the sand and gravel bordering the Cuyahoga Valley at an altitude near that of Lake Wayne is due to the action of the stream while this lake was forming the shore line just described, and that when the water rose to the level of Lake Warren the river graded the delta about 20 feet higher. Many years ago the bones of an elephant were found at a depth of about 10 feet underneath the shore of Lake Warren in the central part of Cleveland.[8a] It is probable that the burial of the bones to this depth under deposits of gravel was due to the building up of the delta after the rise of the water from the level of Lake Wayne to that of Lake Warren.

*Shore of glacial Lake Warren.*—In the Cleveland area the shore of glacial Lake Warren followed North Ridge from the west side of the Berea quadrangle eastward to the Rocky River. This ridge is of gravelly constitution for about 3 miles in the western part of the quadrangle and for a short distance west from the Rocky River, but generally it is merely a cut in the shale or the till near the top of the lake cliff that had been previously cut by Lake Wayne. East of the Rocky River the cuts in the shale made by Lake Warren lie in places a quarter of a mile south of the lake cliff cut by Lake Wayne. In the eastern part of the Berea quadrangle the shore of Lake Warren is close to that of Lake Wayne, but on entering the Cleveland quadrangle the Warren shore takes on a double phase and is represented by gravel ridges. The outer ridge lies a short distance north of

[8a] Hay, O. P., Carnegie Inst. Washington Pub. 322, p. 136, 1923.

Lorain Avenue from a point near the west side of the quadrangle eastward about to West Forty-fourth Street. It there crosses the avenue and lies a short distance south of it to the bluff of the Cuyahoga River. The inner ridge follows the line of Detroit Avenue to the river bluff.

East of the Cuyahoga River the Warren shore is represented by two beaches, each composed of sandy gravel. The outer one, known as the Woodland Avenue beach, runs along or near Woodland Avenue from the vicinity of the Cuyahoga River eastward beyond Woodland Cemetery and then bears north of east away from the avenue and continues for a mile or more farther. It stands about 680 feet above sea level.

The inner Warren shore line east of the Cuyahoga River is known as the Euclid Avenue beach and runs along or near Euclid Avenue to a point within a mile of Wade Park. It there takes a course north of east a short distance north of the avenue and runs through the southern part of Wade Park to a point near the western limit of Lakeview Cemetery as a definite gravelly ridge. From the cemetery northeastward through the Euclid quadrangle there is not so definite a gravel ridge as on the west; it is merely a thin coating of sand and gravel on a terrace cut in shale. The terrace is utilized by Euclid Avenue throughout the distance, so that the name "Euclid Avenue beach" is applicable clear to the eastern limit of the Euclid quadrangle.

*Lake bed between the Wayne-Warren shores and the Grassmere beach of glacial Lake Lundy.*—Between the Wayne-Warren shores and the Grassmere beach there is a strip of land, about 2 miles wide at the west side of the Berea quadrangle but narrowing to about half a mile at Dover Bay, which has a very heavy clay soil, with shale at slight depth. From Dover Bay eastward to the Rocky River, where there is a thick deposit of drift in the preglacial valley of the river, the soil is of much looser texture. From the east side of the Rocky River to the west edge of the Cleveland quadrangle there is also a heavy clay with shale at slight depth, extending from the Wayne shore to the bluff of Lake Erie, which is there as high as the Grassmere beach. From Edgewater Park eastward to the mouth of the Cuyahoga there is a heavy drift filling, and the soil is of loose texture, in places sandy. East of the Cuyahoga there is sandy soil about to the mouth of Nine-mile Creek, but from that stream eastward there is a heavy clay soil with shale at a slight depth nearly all the way to the east limit of the Euclid quadrangle.

*Grassmere beach of glacial Lake Lundy.*—Glacial Lake Lundy, the next lake stage after Lake Warren, takes its name from a beach near Niagara Falls, Ontario, along and near which was fought the Battle of Lundy's Lane. Its highest shore, the Grassmere beach, where unaffected by later disturbance has an altitude of 635 to 640 feet above sea level. There is a lower shore line, known as the Elkton beach, standing at about 620 feet, which is also referable to Lake Lundy, as it pertains to an eastward-draining lake. The lowering of 15 to 20 feet is due either to cutting down of the outlet or to a slight shifting at some place in its course.

In the Cleveland area the Grassmere beach has its best representation in the Euclid quadrangle. A sandy ridge is traceable from Doan Brook northeastward past Collinwood and Nottingham to Noble. Eastward from Ninemile Creek the sandy strip traverses a clay district, but west of that stream the border district is sandy. The sandy ridge is not uniform in altitude and is broken and irregular. In some places it is below 640 feet and in others as high as 650 feet above sea level. The sand probably was deposited along the lake shore at 635 to 640 feet and then shifted by the wind to a slightly higher level on the slope back of its shore. The sand is nearly free from pebbles and might be easily moved by the wind.

Within a short distance west of Doan Brook the bluff of Lake Erie rises above the level of Lake Lundy, and there are a few places between that point and the mouth of the Rocky River where Lake Lundy extended beyond the present shore. Westward from the Rocky River as far as Cahoon Creek there is a space scarcely a quarter of a mile wide between the shores of Lake Lundy and Lake Erie. The shore of Lake Lundy thence bears away from Lake Erie and is fully 2 miles inland at the west side of the Berea quadrangle.

The Grassmere shore is a very faint feature, in places scarcely detectable, especially where it is cut in shale. Where sandy the ridge is only 2 to 4 feet high. Near the west edge of the Berea quadrangle it presents an unusual phase, being there a very bouldery ridge scarcely 3 feet high and about 50 feet wide. There is no sand or gravel in the ridge but instead a stiff clay, like that of the bordering plain. The ridge has a northeast trend and crosses the road leading south from Avon Lake about one-third of a mile north of the New York, Chicago & St. Louis Railroad. Its altitude seems to be about 635 feet above sea level. It is the only ridge of this sort noted in the entire Cleveland district.

*Elkton beach of glacial Lake Lundy.*—The Elkton beach has an altitude of about 620 feet where it is unaffected by differential uplift. It lies at this level near the west edge of the Berea quadrangle on the road leading south from Avon Lake, two residences standing on it. It there consists of a slight ridge that rises about 2 feet above the border plain and stands out with remarkable clearness where it crosses the road. It is composed of clayey material similar to that of the bordering plain but is not bouldery like the ridge on the south. There seems to have been no coarse material in the surface deposits here for the waves to sort out and concentrate as sand or gravel. The plain is low enough to be covered by water at this lake stage for only about 2 miles eastward from the west side of the Berea quadrangle, so the beach has but slight representation in this part of the Cleveland district. In the Euclid quadrangle, from a point near East One hundred and fifth Street eastward to the limit of the quadrangle, there is a strip half to three-quarters of a mile wide that is low enough to have been covered by the lake at the Elkton stage, but no definite shore features were noted on it along or near the 620-foot contour. From Ninemile Creek eastward the soil is clayey, and the beach is likely to be difficult to identify now that the surface has been greatly modified by ditching and grading.

*Lake bed between the Lake Lundy shores and Lake Erie.*—The lake bed between the bluff of Lake Erie and the shores of glacial Lake Lundy is generally clayey, but where glacial deposits are thick over the old bed of the Rocky River and just east of Eagle Cliff the soil is of looser texture and is classed as sandy loam on the map issued by the Bureau of Soils.

*Early stages of Lake Erie.*—Lake Erie was established by the separation of its waters from those of the Ontario Basin at the Niagara escarpment. The lake endured various further changes before the present stage was reached, but the successive bodies of water have left little record within the Cleveland area. A general account of them is given under the heading "Postglacial lake" (pp. 100–103).

*Present shore line of Lake Erie.*—The contours on the maps show that the shore is largely a lake cliff, standing in places 70 feet and at few points less than 35 feet above the present lake level. It consists of shale in much of the Berea quadrangle but of glacial and lake deposits in the Cleveland and Euclid quadrangles. The rate of erosion is a little more rapid where the bluffs are of till in the Berea quadrangle than where they are cut in shale. Consequently there are slight embayments at the mouth of the old Rocky River and at the till bluffs east of Eagle Cliff. The lake is now cutting into its shore at a rapid rate, because of the rise on its shore. Whittlesey [9] stated that from 1796 to 1842 the encroachment of the lake on the shore opposite the public square in Cleveland reached 265 feet, or nearly 6 feet a year. Soon after this period action was taken by the city government, aided by railroad companies, to stop the encroachment in the main part of the city, but it is still going on rapidly at points near the eastern and western limits of the Cleveland district.

[9] Whittlesey, Charles, Smithsonian Contr. Knowledge, vol. 1, art. 3, p. 25, 1867.

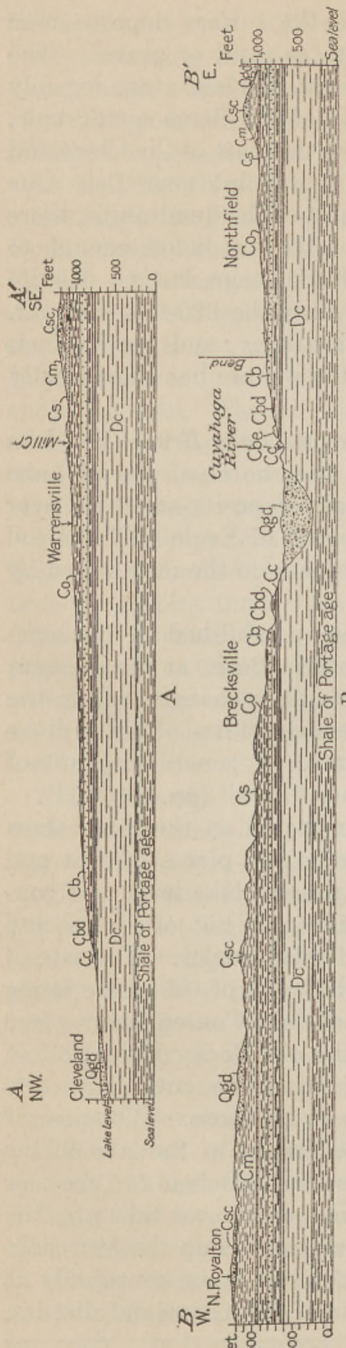


FIGURE 6.—Sections across Cleveland quadrangle. A-A′, through Northfield, Brecksville, and Royalton. B-B′, from Cleveland to Warrensville, from the marginal plain at the west to the level of the Harrisburg peneplain. For explanation of symbols of formations see geologic map (pl. 20)

## STRUCTURE

By H. P. Cushing

The rocks of northern Ohio are little disturbed from their original, nearly horizontal position. (See fig. 6.) The dip is very slight and variable, both in amount and in direction. Owing to convergence of the Berea sandstone and the Delaware limestone and unconformity at the base of the Sharon, the dip also varies with the rock horizon. The normal dip of the surface rocks is southeast, away from the Cincinnati dome and from the Canadian old land; and this is the direction of the dip of the Devonian limestones and of the still older rocks, as the well records show. In contrast to this position the surface rocks in the northern portion of the Cleveland district dip southwest, and those in the southern part south-southeast.

The southerly dip of the rocks across the Cleveland district is about 5 feet to the mile, much less than the normal southerly dip for eastern Ohio, which is from 15 to 20 feet to the mile. The dip rapidly increases, however, to its normal amount in the quadrangles next south of this district. Such variations indicate slight warping or folding of the district along east-west axes.

The westerly component of the dip of the Mississippian rocks across the district is also variable. Across the Cleveland quadrangle it is less than 5 feet to the mile. Between Big Creek and the Rocky River it steepens abruptly to nearly 15 feet to the mile. West of the Rocky River it diminishes again and at the west edge of the Berea quadrangle is nearly flat, so that the dip is south instead of southwest. Such variations indicate slight warping along north-south axes that cross the other set at about right angles.

Figure 7 illustrates the manner in which the dips vary with the rock horizon. In the practically east-west line between Bedford and Olmsted Falls, a distance of 18 miles, the base of the Berea sandstone drops in altitude 150 feet in a westerly direction, whereas the summit of the Devonian limestones drops 180 feet in an easterly direction. Actually the Berea dips southwest and the Devonian limestones southeast. If the base of the Niagara limestone is taken for the datum plane instead of the summit of the Devonian limestones the easterly

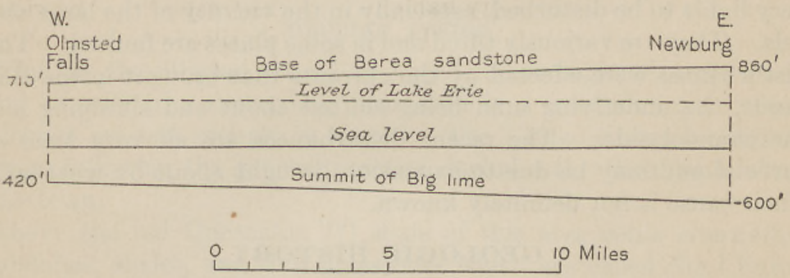


FIGURE 7.—Diagram illustrating east and west dips between Bedford and Olmsted Falls. Horizontal scale, 1 inch=5 miles. Vertical scale, 1 inch=2,000 feet, thirteen times the horizontal scale. Figures at the side represent distances above or below sea level of the Berea base and Big lime summit at Olmsted Falls on the left and at Newburg on the right

dip is found to be still greater. It is the rapid thinning of the shales of Portage age and the overlying Chagrin shale in a westerly direction, more than 300 feet in the 18 miles, that accounts for this difference in direction of dip between the higher and lower rocks. Likewise it is the rapid thinning of the Salina formation toward the west that explains the discrepancy in the amount of dip between the summit of the Devonian limestone and the base of the Niagara.

The Sharon lies nearly flat across the district, because the increasing thickness of Meadville rocks underneath it in passing westward, due to unconformity at the top, just compensates for the dip of the Berea in the same direction.

These warps have an influence in determining the boundaries of the gas territory west of Cleveland. The productive territory occurs in areas where the dips in the gas sand are flatter than the normal. Such areas, as shown in Plate 19, occur on a broad terrace or nose. Across all three quadrangles the southward dip is much less than the normal amount for the eastern half of the State. As the Mississippian rocks at the surface dip southwest and the limestones below ground dip southeast, it is obvious that a warp that increases the steepness of dip of the former must correspondingly diminish that of the latter. In other words, where the surface rocks have their steepest south-westerly dips those below ground would have their flattest. Such an area of increased southwest dips of the Mississippian rocks occupies the eastern two-thirds of the Berea quadrangle, and there the under-ground limestones must have a corresponding diminution in their southeast dip, hence must lie flatter than usual. This is the region of gas production, a region where the dip, whether measured along an east-west or a north-south line, is much less than the normal.

The soft shales of the district in many places exhibit minor disturbances, both folding and thrust faulting. These are all of small extent, some of them are old and some very recent, and they have arisen from different causes. The shales at the base of the Berea are very liable to be disturbed, especially in the vicinity of the large channels. They are variously tilted and in some places are faulted. These disturbances were effected by the currents that brought in the Berea sands, the underlying mud being shifted about and slumping along the channel sides. The recent disturbances are all very local and surficial and may be due to expansion brought about by weathering. Their cause is not definitely known.

## GEOLOGIC HISTORY

Beyond the bare statements that the Cleveland district had a pre-Cambrian history whose records are wholly buried beyond our reach; that it no doubt shared in the general uplift of the continent at the end of pre-Cambrian time and remained a land area for a long interval; that it became submerged beneath the shallow waters of an Upper Cambrian sea; and that this submergence was followed by others in Ordovician time, nothing can be said as to its early geologic history. The lower 1,170 feet of rock in the Lorain well is of Ordovician age, but just what Ordovician groups are represented there it is impossible to say. The well record shows that the district was submerged during much of the Ordovician period and that a large thickness of deposits was formed. Probably the Trenton, Utica, Eden, and Maysville are all represented by deposits, showing submergence of the region during those epochs.

### PALEOZOIC ERA

By H. P. Cushing

#### ORDOVICIAN PERIOD

The oldest of the underground formations that is recognizable with any degree of certainty is the red shale, which is probably referable to the Queenston shale, of Richmond age, a formation whose nearest surface outcrops are those along the Niagara River and in Ontario.

These red shales are unfossiliferous and seem to represent a near-shore phase of the Richmond, laid down in shallow water on a slowly subsiding bottom, under conditions very unfavorable to life. The typical Richmond rocks, which are widely exposed in the region around Cincinnati, where they are full of marine fossils, were deposited farther offshore.

At the end of the Ordovician period the Cincinnati arch was domed and elevated above sea level as part of a general withdrawal of the sea that then took place. This arch has since remained as a positive feature of the continent, continuing as a land area or a submerged shoal throughout the remainder of the Paleozoic era. That the Cleveland district was also brought above sea level at this time is not definitely known, though regarded by many geologists as highly probable. If it was, the land was low and was not greatly eroded.

### SILURIAN PERIOD

Whether the Silurian should be considered to begin with the Richmond or with the succeeding formation is a question upon which geologists are not entirely in accord. The United States Geological Survey, following the general practice, includes the Richmond in the Ordovician.

Above the red Queenston (?) shale of this area come alternating sandstones, shales, and thin limestones which are called the Clinton formation and which include the so-called Clinton gas sand but are probably referable in whole or large part to the Albion sandstone, a formation that underlies the true Clinton formation of New York. It is not known whether true Clinton beds are present or not, nor whether the district was continuously submerged or emerged one or more times during the interval. If it was emergent, depression followed, and clear, open marine conditions prevailed, during which the considerable thickness of limestones of Niagara age was laid down. This subsidence was long continued and widespread, and the clear waters of the sea were thronged with numerous and varied forms of life.

After the Niagara epoch the sea largely withdrew, and the district was occupied by landlocked waters, presumably near or at sea level, surrounded by very low lands. The climate became arid and caused the conversion of the water bodies into one or more salt lakes in which mud and thin beds of limestone were deposited, then beds of gypsum, and, in local areas where there was great concentration of the saline waters, beds of rock salt. The series of deposits is repeated several times and suggests corresponding variations in concentration of the waters, possibly due to fluctuation in the amount of rainfall. Under such conditions the Salina beds, of early Cayugan age, were laid down. The Salina waters covered a large part of New York and

Pennsylvania and also northeastern Ohio. The characteristic deposits cease a few miles west of the Cleveland district. Whether the waters were there but deposited no salts, or whether western Ohio was above the water level of the time and received no deposits, as the writer thinks, is a matter upon which geologists disagree.

After the Salina epoch the climate became less arid and the submergence more extensive, and under these conditions the water limes and some gypsum beds of the Bass Islands dolomite were deposited. The gypsum beds show that the climate was still arid, but the waters never became as concentrated as during the Salina and were often fresh enough to support a fauna, which however, was not a normal marine fauna but one of a few types that were adapted to thrive in the unusually salty waters of the basin.

### DEVONIAN PERIOD

*Sylvania and Lucas submergence.*—The succeeding Sylvania sandstone testifies to a great change in physical conditions. The excellent sizing of the grains, together with their rounded shapes and etched surfaces, certainly indicates that the sand was blown by winds and suggests desert conditions on neighboring lands and the continuance of climatic aridity. Whether the sand was deposited in water or on dry land is not certainly known, but the great contrast between the sandstone and the limestone above and below demonstrates a great change in physical conditions and argues for emergence of the district during the Sylvania epoch.

Renewed depression brought on the deposition of the Lucas dolomite. This also suggests deposition in a partly inclosed basin during climatic aridity and mostly in shallow water. In the upper part of the formation beds of limestone carrying a marine fauna appear. The district came above sea level at the end of the Lucas epoch and existed as an area of low land for a long time.

*Onondaga submergence.*—The Onondaga sea of the Middle Devonian was the next marine water to overspread the district. The land had been thoroughly base-leveled during the emergent period just preceding, so that the shallow Onondaga seas spread rather widely. The lands that bordered it were low and incapable of supplying much land wash, so that the waters were clear and peopled with an abundant marine fauna and supported extensive local coral reefs. The reefs indicate warm waters and supply part of the evidence that the marine invasion came from the south.

*Hamilton submergence.*—The limestone of Onondaga age terminates rather abruptly and is directly followed by the blue to brown beds of the Delaware limestone. Conditions in surrounding territory must have changed, as the beds of Hamilton age contain more land wash than those of Onondaga age; hence, the bordering lands must have been more elevated. The land wash may have come from distant Appalachia or from the Cincinnati dome, nearer at hand. The supply was intermittent, especially at first, during the Delaware epoch, but was considerably increased during the succeeding part of the Hamilton epoch. An abundant fauna swarmed in the waters and on the bottom, consisting of Hamilton forms with which are mingled survivors of the Onondaga fauna. The Onondaga forms are abundant in the Delaware, but few remain in the overlying shale of Hamilton age.

*Portage and Chagrin sedimentation.*—The deposition of the beds of Hamilton age was followed by a break in the sedimentation; there was also oscillation of seas, and under the new conditions the formation of the considerable thickness of alternating black and blue shales in the Cleveland district was begun. The abundant land wash, the lack of limestone, and the high content of carbonaceous material show that the bordering lands were even more elevated than in the Hamilton epoch, that the waters were muddy and unfit for abundant life, and that during much of the time the bottom was foul with decaying organic matter. These shales are the thinned westward extension of the Portage formation of New York, and their muds were derived from lands on the north and east and perhaps also from the Cincinnati dome, though there is difference of opinion as to whether the dome was unsubmerged at this time or not. There is also difference of opinion in regard to the extent of this sea, some geologists believing that it extended west to and even over the Cincinnati dome and that these shales are the equivalent of the lower part of the Huron shale of northern Ohio and of the New Albany shale of Indiana and others, including the writer, thinking that the typical Huron is a younger formation that has nothing to do with the black shale of Portage age of the Cleveland district and that the Portage sea did not extend as far west as the Huron River. It must be left for the future to determine which of these conflicting views is true.

The black mud of the Portage sea was succeeded by the gray and blue mud of the Chagrin shale, deposited in the west end of the basin in which the Chemung rocks of New York and Pennsylvania were laid down. There was some oscillation preceding the Chagrin epoch, the bordering lands on the east were raised still higher and supplied coarser land wash to the basin of deposit, and the bottom also cleared, so that black mud ceased to be formed. In New York subsidence of the bottom of the basin was more pronounced than in the Cleveland district and conditions were more favorable for the existence of marine life, so that a much greater thickness of deposits accumulated, holding an abundant fauna from bottom to top. At Cleveland the mass of the formation is barren of fossils; the fauna did not come into the district until near the end of the period and got no farther west at any time.

### DEVONIAN OR CARBONIFEROUS SUBMERGENCE

The events that directly followed Chagrin deposition in northern Ohio are not established beyond controversy. According to one view, uplift followed the Chagrin epoch, and the entire district became a land area of low altitude and so remained for a long time, during which its surface was gently beveled off by erosion. The break is held to be the most significant one within the general series and to mark the line of division between the Devonian and Carboniferous systems. It is the writer's belief that when subsidence recommenced and deposition of the black mud of the Cleveland shale began, the marine invasion came from the south into western Ohio, where the Huron shale was deposited in a narrow bay along the east side of the Cincinnati dome. The waters slowly spread eastward, depositing the lower division of the Cleveland shale upon the Huron and farther east upon the Chagrin, and last of all laid down the upper division of the Cleveland in waters that rapidly spread farther east. Even at this greatest extent, however, the waters did not reach into Pennsylvania.

According to the other view there is no break, or none of much extent, between the Chagrin and Cleveland shales, but they are held to be deposits from the same body of water, blue Chagrin shale being deposited on the east while black Huron shale was forming at the west, and as Chagrin time went on black shale gradually spread eastward at the expense of the blue shale. The basis for this view is the fact that the blue shale grades into black shale toward the west, and the black shale is therefore held to be of late Devonian age.

*Cleveland sedimentation.*—Deposition of the black mud of the Cleveland shale began earlier in the Berea quadrangle than in the Cleveland and slowly spread eastward. The adjacent lands were low but high enough to furnish a supply of mud to be laid down in the subsiding basin. The bottoms were foul with decaying organic matter, and the marine forms that live on the bottom and subsist on such matter were therefore absent, and their fossil remains are not found in the shales. The surface waters were purer, and life swarmed there, notably the fishes, large and small, whose remains are found in the shales.

*Bedford sedimentation.*—Sedimentation was interrupted at the end of the Cleveland epoch, and some warping took place in the adjacent lands, which became higher locally and capable of furnishing coarser land wash. Possibly the sea withdrew and then returned, but no conclusive evidence has yet been found that it did so. The stagnant and foul bottom waters, however, became stirred and purified by stronger currents than had existed in Cleveland time, and these currents locally stirred up the black mud and relaid it as the initial deposit of the Bedford. With the sweetening of the waters a bottom fauna entered the basin and lived most abundantly where the bottom mud was least stirred by currents. But the organisms were mostly small forms with thin shells that were badly broken up by the moving water. Soon the rate of the coming of mud into the basin increased, and locally stronger currents swept in and deposited great lenses of fine sand. The muddied waters disagreed with the fauna, which dwindled and vanished rather early, so that the waters of the basin during the greater part of Bedford time held but little life. The waters probably entered from the south, and the basin was landlocked on the west, north, and east sides. Neither the formation nor its fauna are known in western Pennsylvania. Rapid deposition seems to have quickly shallowed the basin, and the upper part of the Bedford, particularly the red Bedford, suggests deposition on shallow mud flats during climatic aridity.

## CARBONIFEROUS PERIOD

### MISSISSIPPIAN EPOCH

*Berea sedimentation.*—At the end of the Bedford epoch an uplift of the lands on the north and west carried the Cleveland district above sea level and converted it into a low plain but with a surface gradient sufficiently steep and with bordering lands sufficiently high to enable the streams to bring down quantities of sand. The transporting currents channeled away the underlying muds of the Bedford and filled the excavations with sand, the channels being deepest where the land was highest—that is, at the northwest. The sands were spread broadly over the low plain that formed the general delta region. Abundant fragments of land plants were brought down by occasional floods and buried in the sands, and lumps of wet clay were also transported and deposited. Floods also brought down schools of fresh-water fishes, some of which became stranded in pools on the delta surface as the flood waters fell, were killed by the drying up of the pools, and were covered by the sands of another flood and preserved as fossils. The numerous specimens of the fossil fish *Gonatodus brainerdi* found on the surface of a single layer in a single locality at Chagrin Falls are to be accounted for by some such process.

While the delta formation was being laid down in the Cleveland district the southeast slope of the land caused the deposits to be made beneath sea level in that direction, and this delta formation thus grades laterally into a finer-grained sandstone that carries marine fossils, as the Berea does in western Pennsylvania and in southern Ohio. During Berea time slow subsidence was in progress, and the sea came nearer and nearer to the Cleveland district, so that in the final stages of the deposition the delta surface was approximately at sea level, and storm waves could occasionally sweep in over this surface and bring a few worn marine shells to be deposited upon and be covered by the sand.

In contrast with that of the Bedford the Berea climate seems to have been moist and cool, as suggested by the abundant plant fragments and their carbonized condition and by the clay lumps found in the sands.

*Orangeville sedimentation.*—Continued depression, which lowered the adjacent lands, brought about a cessation of the sand supply and terminated Berea deposition. A renewal of marine conditions in northern Ohio followed. The waters slightly reworked the surface material of the Berea and produced from it a thin sandy stratum that subsequently became cemented by pyrite and forms the peculiar black layer of sand that is everywhere the Orangeville base. There was a break in sedimentation as one set of conditions passed into the other, but only for a short time. Then mud began to be washed into the subsiding basin, but the process was soon interrupted for a brief time by the incursion of sand that forms the thin Aurora sandstone near the base of the formation. The deposition of mud was quickly resumed and continued with little variation until the full thickness of the formation had been deposited. The conditions were those of black shale formation, including quiet water and foul bottom from decaying organic matter. Bottom life was scarce, but swimming forms, including large sharks, thrived, especially early in the epoch.

*Sharpsville and Meadville submergence.*—The black shales of the Orangeville are followed by the sandy beds of the Sharpsville. The change in sedimentation indicates oscillation and increased altitude in the bordering lands. The sharpness of the break suggests a pause in sedimentation, though there is no evidence of uplift, and the interval seems to have been very brief. The Sharpsville currents cleared out the foul waters of the Orangeville basin, and a fairly abundant fauna came in. Fragments of land plants are common, showing that the northern shore of the Sharpsville basin was not far away. The basin gradually deepened, and the sand was followed by the mud of the Meadville shale, with occasional incursions of sand that became more frequent in the later stages of Meadville time. Conditions were more favorable for an abundant marine fauna than any that had prevailed in the district since Onondaga and Hamilton time, and they became steadily more favorable as Meadville time went on. Yet barren beds alternate with the fossiliferous beds, hence it is evident that conditions varied and the fauna increased or diminished as they changed.

Nothing positive can be said concerning the climatic conditions that prevailed in the district during Orangeville and Meadville time. In discussing beds of about the same age in Michigan, Lane [10] states that "the abundance of mica and sand indicates rapid land waste and rock decay, while the abundant bits of vegetation show that there was abundant plant life. Both facts point to a relatively humid climate." These conclusions seem probable and applicable to the Meadville, whose climate was very likely moist and cool, though less markedly so than that of the Berea. It was tending toward the arid condition that followed.

*Later Mississippian time.*—In the Cleveland district no record remains of any deposits that may have been formed between the end of the Meadville and the beginning of Sharon deposition. The Black Hand and Logan formations of central Ohio lie above the Meadville, and their character indicates increased slopes in bordering lands, so that the streams carried coarser, often much coarser material. As these formations are present 25 miles to the south, it is possible that they were deposited over the Cleveland district and then worn away before the Sharon was laid down. It is also possible that the sea was withdrawn from the district at the end of the Meadville epoch and so remained during Black Hand and Logan time. The former alternative requires more erosion than the latter to produce the surface upon which the Sharon was deposited and allows less time in which to do it. The sea was certainly withdrawn at least as early as the end of the Logan epoch, the entire district becoming land.

A later Mississippian submergence, which was most prolonged in the region of the Mississippi Valley, involved southern and central Ohio for a time, and a thin deposit of calcareous mud, now the Maxville limestone, was laid down in a clear, shallow sea, but there is no evidence that this invasion reached as far north in Ohio as the Cleveland district. During this later part of the Mississippian epoch the climate became arid, and there was a salt lake in the Lower Peninsula of Michigan, where gypsum and rock salt were deposited during part of the time. At the end of the Mississippian epoch the sea was withdrawn over a wide area. The Cleveland district had become gently warped along an axis of elevation that coincides with the Chagrin Valley, and the warped beds were deeply truncated by erosion during this interval. The entire thickness of the Meadville shale was worn away along the axis of the warp, and much of its thickness elsewhere. If the Black Hand and Logan were deposited in the Cleveland district they were completely eroded away at this time.

[10] Lane, A. C., Michigan Geol. Survey, vol. 7, pt. 2, p. 23, 1900.

### PENNSYLVANIAN EPOCH

*Pottsville time.*—Eastern Appalachia increased in altitude as a phase of the uplift that ended the Mississippian sedimentation, and from this elevated land great quantities of gravel and sand were carried down and spread out on the lower grounds on the west, beginning the Pottsville deposition. These early continental deposits of the Pennsylvanian epoch were confined to the Appalachian troughs but slowly spread westward and in the latest part of Pottsville time reached Ohio, and the gravel and sand that now form the Sharon conglomerate were then laid down. The deposit is distinctly of continental, not marine nature. The method of formation of this coarse gravel, whose pebbles must have come from a great distance, has never been satisfactorily explained. It bears a resemblance to some glacial gravel, and Newberry long ago invoked glacial ice as the agency for the transportation of the material. The explanation is possible, but the proof is yet lacking.

After the deposition of the gravel and sand swamps covered much of the district, and the vegetal accumulation that now forms the Sharon coal was deposited. This was followed by recurrent deposition of sand, mud carrying many lime-iron concretions, marine limestone, coal, and iron carbonate. These upper formations have since been entirely eroded away from the Cleveland district but are found in the quadrangles next to the south and unquestionably were originally deposited here.

*Remainder of Pennsylvanian time.*—During the remainder of Pennsylvanian time eastern Ohio was flat and close to sea level, most of the time above but occasionally somewhat below it. Deposits of lime mud and of clay mud were laid down in the periods of submergence, in part in marine waters, in part in brackish waters of estuaries. At other times, possibly in periods of emergence, sand deposits were laid down, probably as deltas. There were times also when large parts of the surface were covered with swamps, in which plant débris accumulated. Streams crossing the swamps occasionally washed away the débris from their channels, to be deposited elsewhere, and filled the channels with sand. With the passage of long time these vegetal accumulations have become altered into the coal beds.

In eastern Ohio and Kentucky, western Pennsylvania, and West Virginia such beds, each of slight thickness, were deposited before the end of Carboniferous time, making a total thickness of nearly 3,000 feet. The surface of the accumulating mass maintained its closeness to sea level throughout, so that it must have undergone a slow, progressive subsidence, which about kept pace with deposition. Eastern Ohio was in the western part of the basin and received a small thickness of such deposits. The Cleveland district may have been near enough to the western margin to receive only a very little material or even no deposit at all, though its altitude was probably very low. Denudation of the surface since Carboniferous time has removed all trace of beds later than the Sharon conglomerate, and it is very problematical how great a thickness of later beds was ever deposited here. The deposits were sufficiently heavy, however, to crush some of the quartz pebbles in the Sharon.

In strong contrast to the climatic aridity of late Mississippian time, the Pennsylvanian climate must have been moist in order to permit the abundant and varied terestrial vegetation.

### DEFORMATION OF THE STRATA

The final stages of the Paleozoic era witnessed a great deformation in eastern North America, which consisted of folding and faulting in the Appalachian region and of uplift and slight folding in the region to the west. This deformation but slightly affected the Cleveland district, except that it carried the area well above sea level, where it has remained ever since. The amount of uplift is unknown but was at least several hundred feet. The warping of the rocks was slightly increased beyond that which they suffered at the end of the Mississippian epoch and earlier. The chief effect was to uplift the region bodily, in diminishing amount from east to west, giving it a general slope to the northwest and west and causing the original streams of the time to flow in the same directions.

## MESOZOIC ERA

By H. P. Cushing

In the Cleveland district all the topographic features produced by the erosion of early Mesozoic time seem to have been obliterated by later wear, and the general course of events must be inferred from that of other parts of the Appalachian province, where such features yet remain. At the beginning of the era the surface of eastern Ohio must have stood at least several hundred feet above sea level and sloped to the west or northwest. The main streams had their sources far to the southeast, near the axis of uplift, and flowed across the district in a general westerly or northwesterly direction. The time was long, and the district seems to have been worn down to a nearly featureless plain that lay not far above sea level, to have been reelevated, and to have been once more worn down. There is no evidence that it passed beneath sea level during this time, and no trace of the earliest Mesozoic plain remains in the district. The second plain, which was formed by erosion during the Cretaceous period, is approximately represented by the summit levels of the remnants of the

Appalachian Plateaus of northern Ohio. Near the end of Cretaceous time this peneplain was again uplifted, forming a low plateau, and the rejuvenated streams immediately set to work to dissect it.

## CENOZOIC ERA

### TERTIARY PERIOD

By H. P. Cushing

*Erosion of surface.*—The record of Tertiary time in the Cleveland district is wholly a record of erosion. The uplift of the Cretaceous peneplain seems to have been greatest toward the northeast, so that the new plateau had a tilt more to the southwest than its predecessor. But the uplift appears to have been so gradual that the streams cut down their beds as fast as the land rose and thus maintained their previous northwesterly courses. This long-continued erosion so greatly dissected the plateau that, in the Cleveland district, only the high-level tracts which are capped by the Sharon conglomerate can be considered to represent remnants or approximate remnants of its original surface. All the rest of the district had its surface considerably worn down, the new base-level was the level of the Erie Plain, and all the surface of this plain that was underlain by softer rocks was reduced to this new level, 400 feet or more beneath the level of the plateau, which is composed mainly of more resistant rocks. The present bedrock topography of the district is substantially that produced during this period—the base-leveled Erie Plain on the north and the broadly dissected plateau on the south, with wide valleys, low divides, gentle slopes, and rolling surface.

*Late Tertiary elevation.*—Toward the end of the Tertiary period the region was again broadly elevated, and the streams sunk their valleys well below the level of the Erie Plain, many of them much below present drainage level, so that the base-level of erosion was certainly lower than the present lake level and the land was probably so high that a valley was present where Lake Erie now lies. The interval was too short to change materially other features of the topography. The rocks were deeply weathered, and the surface was mantled by a considerable thickness of soil and rock waste.

During the Tertiary period the streams of northern Ohio were much larger than their modern successors, and their sources were more remote. The largest of these streams was the one that flowed northward through the present Grand River Basin and probably carried the whole Monongahela drainage. The Cuyahoga was perhaps next in size and probably carried much of the present Tuscarawas drainage to the north. The Rocky and Chagrin Rivers probably rose farther south and had greater volume than they do to-day.

## QUATERNARY PERIOD

By Frank Leverett

### PLEISTOCENE EPOCH

#### INITIATION AND STAGES OF GLACIATION

Early in the Quaternary period, in what is termed the glacial epoch, a great ice sheet was developed in the northern part of the North American Continent. From a center on the Labrador Peninsula the ice extended southward into the United States, reaching as far southwest as the Mississippi River. At the maximum extension the ice also crossed the Ohio River into Kentucky near Cincinnati and at points below. (See pl. 18.)

The glacial epoch was marked by several stages of glaciation, during which the ice sheets enlarged and spread southward. Between these invasions were stages of deglaciation, when the ice sheets were melted back. Three such glacial invasions of the Ohio region are known to have occurred, with two intervening stages of deglaciation, and there probably have been four glacial invasions. These are designated as follows, beginning with the oldest:

Jerseyan stage of glaciation.
Aftonian stage of deglaciation.
Kansan stage of glaciation.
Yarmouth stage of deglaciation.
Illinoian stage of glaciation.
Sangamon to Peorian deglaciation.
Wisconsin stage of glaciation.

In the Cleveland district the drifts of two of these stages have been distinguished, but deposits of the earlier stages appear to have been largely removed by erosion or completely buried beneath the later drifts. Nearly all the drift of the Cleveland area now open to study pertains to the Wisconsin stage. Interpretations of the conditions that prevailed during the advance of the earliest ice sheets or the recession of their borders must therefore be based chiefly on conditions attending the last ice extension and the succeeding present stage of deglaciation, for conditions similar in general must have characterized the earlier stages.

#### ADVANCE OF THE ICE

Mapping the course of the terminal moraines has shown that the configuration of the margin of the ice sheet of the Wisconsin stage was lobate (pl. 18), with extensions into lowlands and recesses on the uplands. The divergence of striae toward the morainic loops also throws light upon the direction in which the ice advanced across any particular area. In the Cleveland district the striae are found on the exposed surfaces of the sandstones, the shales being too soft to retain them. From the bearings of the striae and from the distribution of the moraines, as shown in Plate 18, it will be seen that the ice that covered the Cleveland district was spreading southeastward toward an interlobate morainal tract between the Grand River lobe on the east and a shoulder of the Scioto lobe on the west.[11]

### DEGLACIATION

In the course of the melting and disappearance of the ice sheet there were oscillations of the ice front forward and backward and not a continuous shrinking of the ice. Some moraines appear to mark positions reached by the ice after a forward movement rather than pauses in the course of the retreat. Several moraines were formed before the ice border had shrunk within the limits of the Cleveland district. The Defiance moraine represents the last notable stand of the glacial front in this region. (See fig. 8.) The Euclid moraine, which has strong development eastward from this area, represents a later position of the border of the Erie lobe.

### HISTORY OF THE GLACIAL LAKES

The long and complicated history of the glacial lakes that occupied the Huron and Erie drainage basins has been set forth in Monograph 53 of the United States Geological Survey. Only a bare outline is therefore given in this place. The relations of the several lake levels along the water front in the Cleveland district are illustrated in Figure 9.

*Glacial Lake Maumee.*—When the ice border in the northwestern part of Ohio held the position marked by the Defiance moraine, the waters ponded in the west end of the Erie Basin discharged to the Wabash River by an outlet leading past Fort Wayne, Ind., commonly known as the Fort Wayne outlet. (See pl. 11.) This early stage of Lake Maumee did not extend eastward as far as the Cleveland district, for the ice still persisted there on all the area below the level of that lake, and Lake Cuyahoga was restricted to the part of the valley south of this area. This highest level of Lake Maumee, about 790 feet above the sea, was maintained until the melting ice on the Thumb of Michigan, west of Saginaw Bay, opened a lower outlet, through which the water was drawn down about 30 feet. At the same time the marginal waters were extended eastward, and Lake Cuyahoga and the lakes in the branches of the Rocky River were merged with Lake Maumee. It was then that the beach known as the lowest Maumee beach was formed. It is represented by Chestnut Ridge in the Berea quadrangle and associated beach deposits at about 760 feet above the sea. The location of the outlet of this lake stage is difficult to determine, because it was subsequently covered

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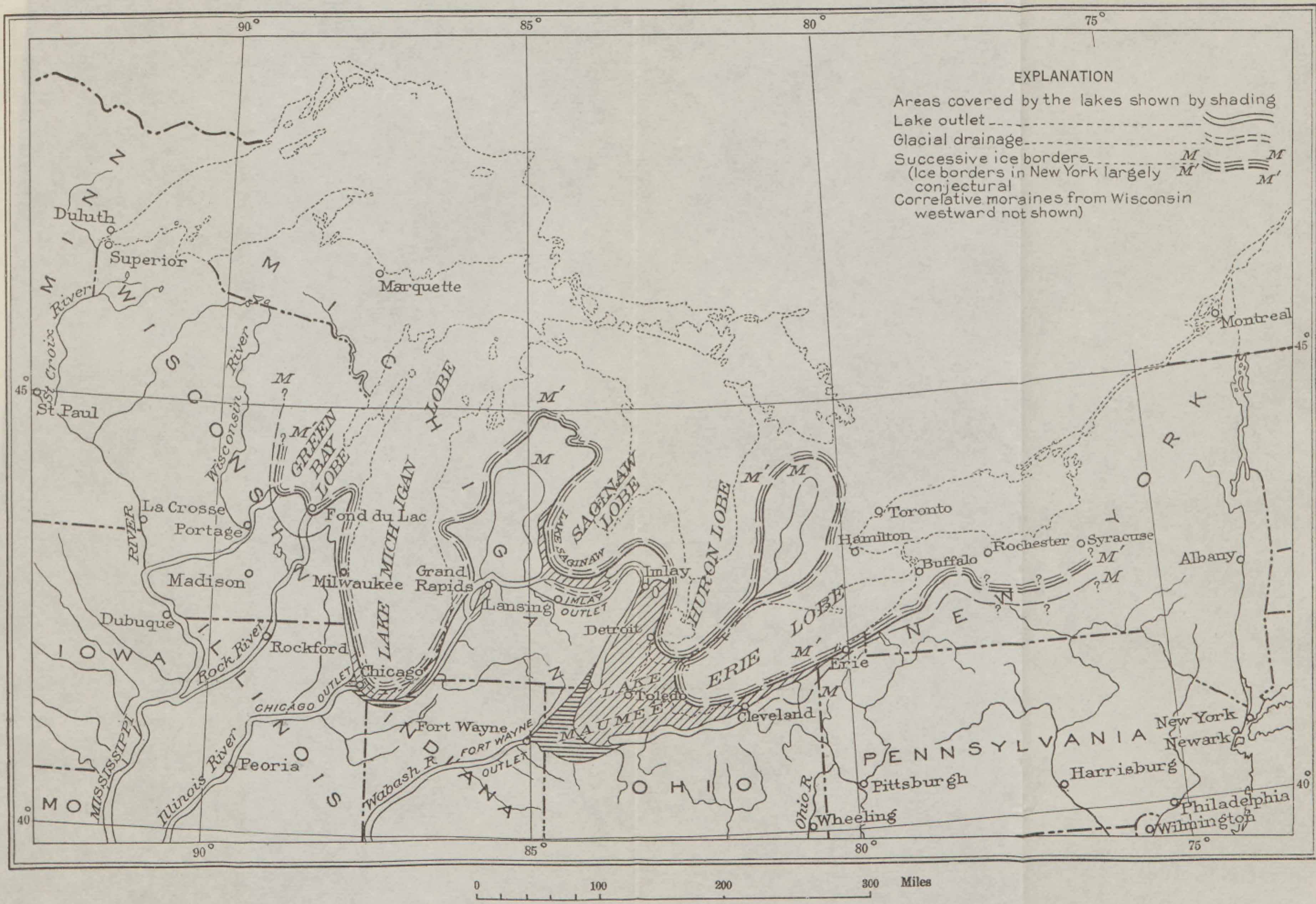
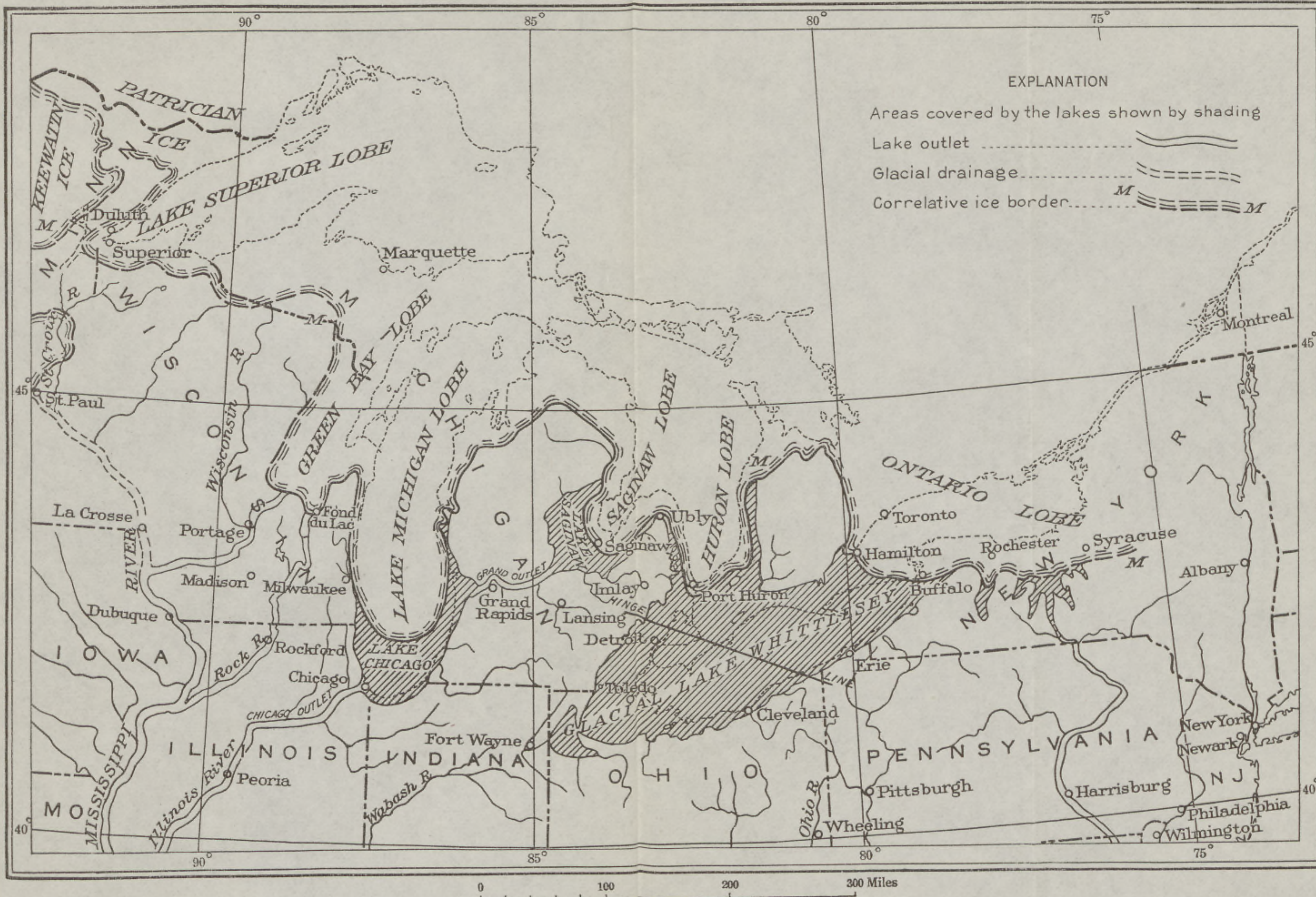
[11] Leverett, Frank, U. S. Geol. Survey Mon. 41, pp. 401–405, 1902.



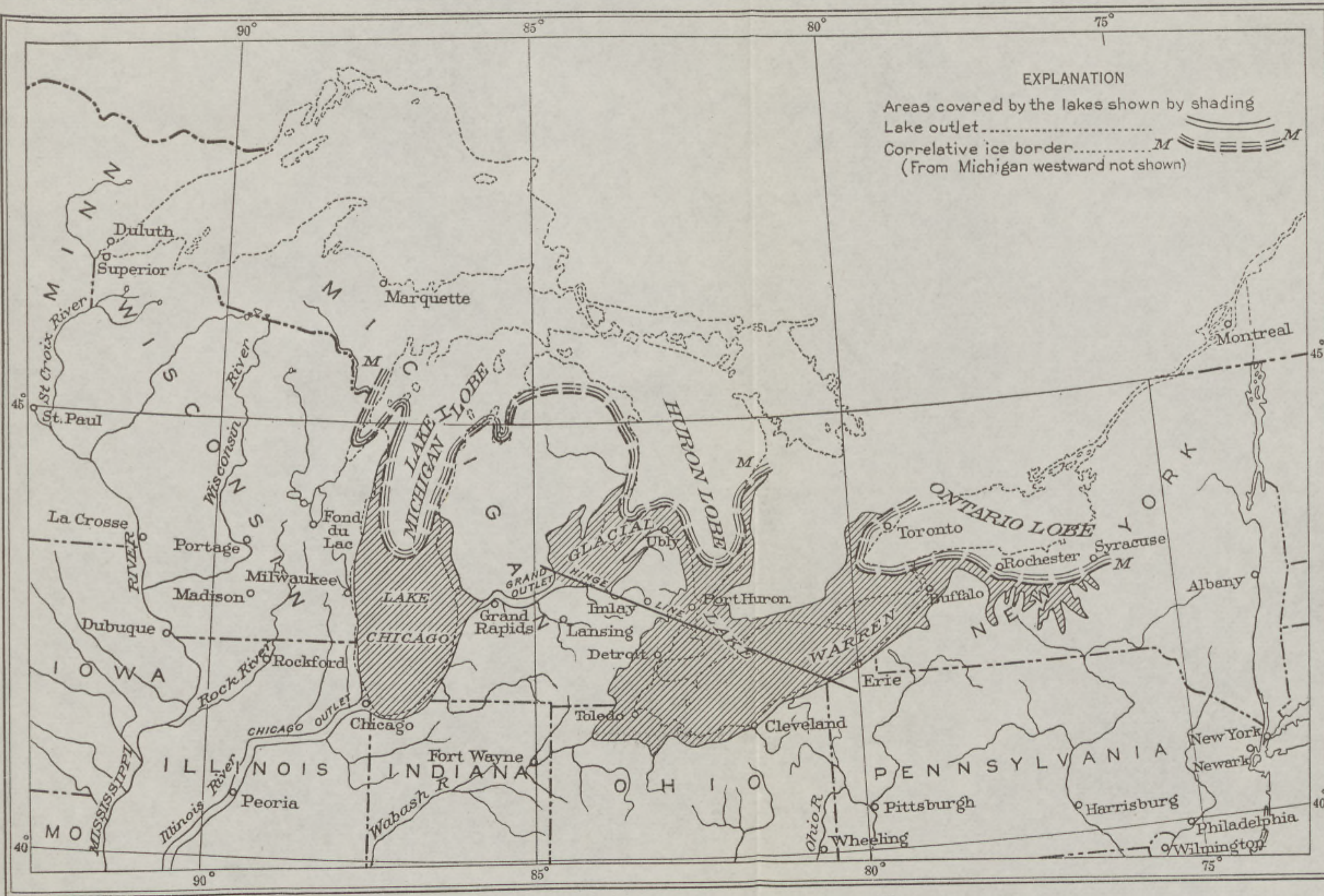

GLACIAL LAKES MAUMEE, SAGINAW, AND CHICAGO

Horizontal shading indicates earlier stages of the lakes; oblique shading indicates later stages. By Frank B. Taylor nd Frank Leverett, 1910.




GLACIAL LAKES WHITTLESEY, SAGINAW, AND CHICAGO

By Frank B. Taylor and Frank Leverett, 1910.

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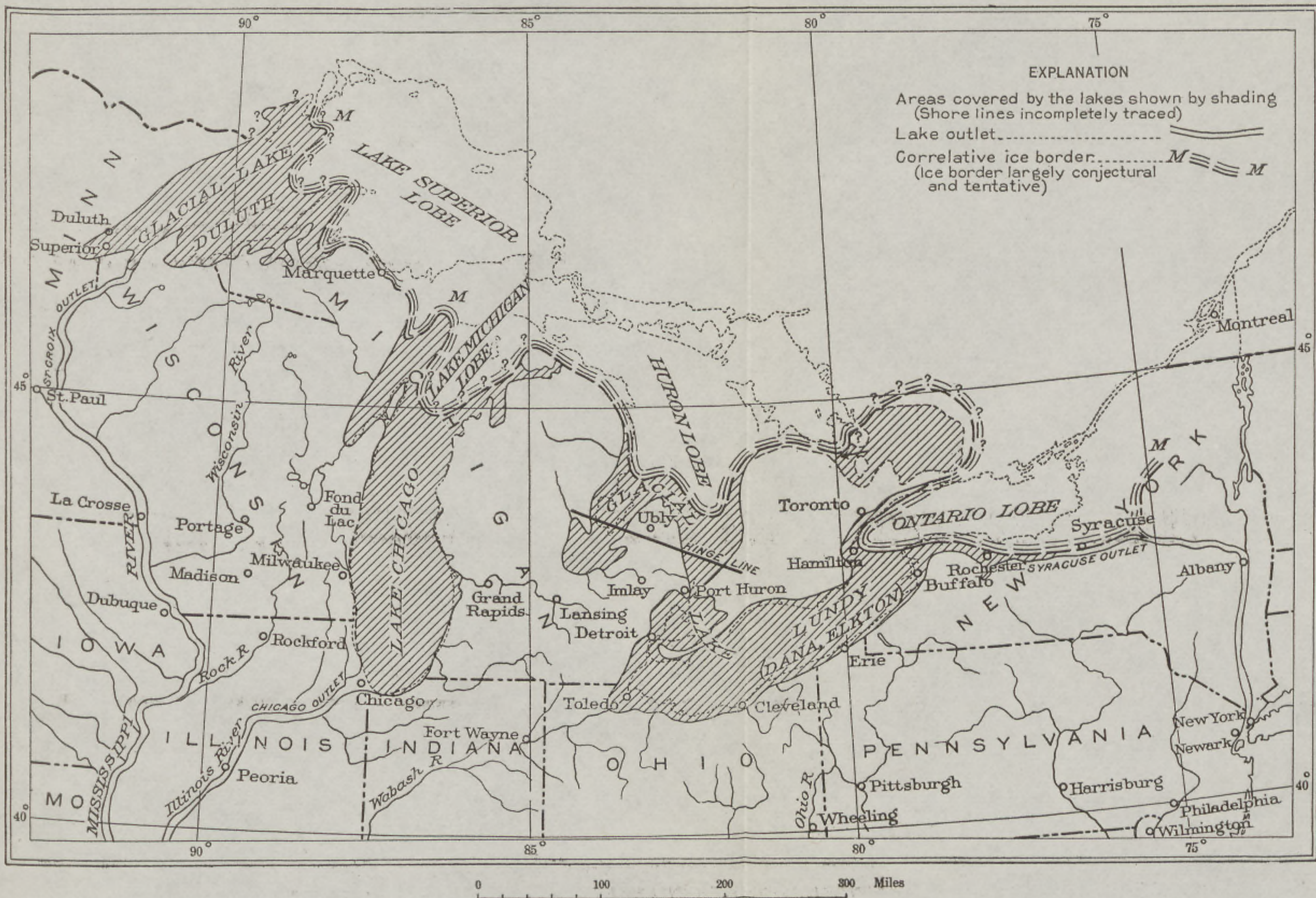
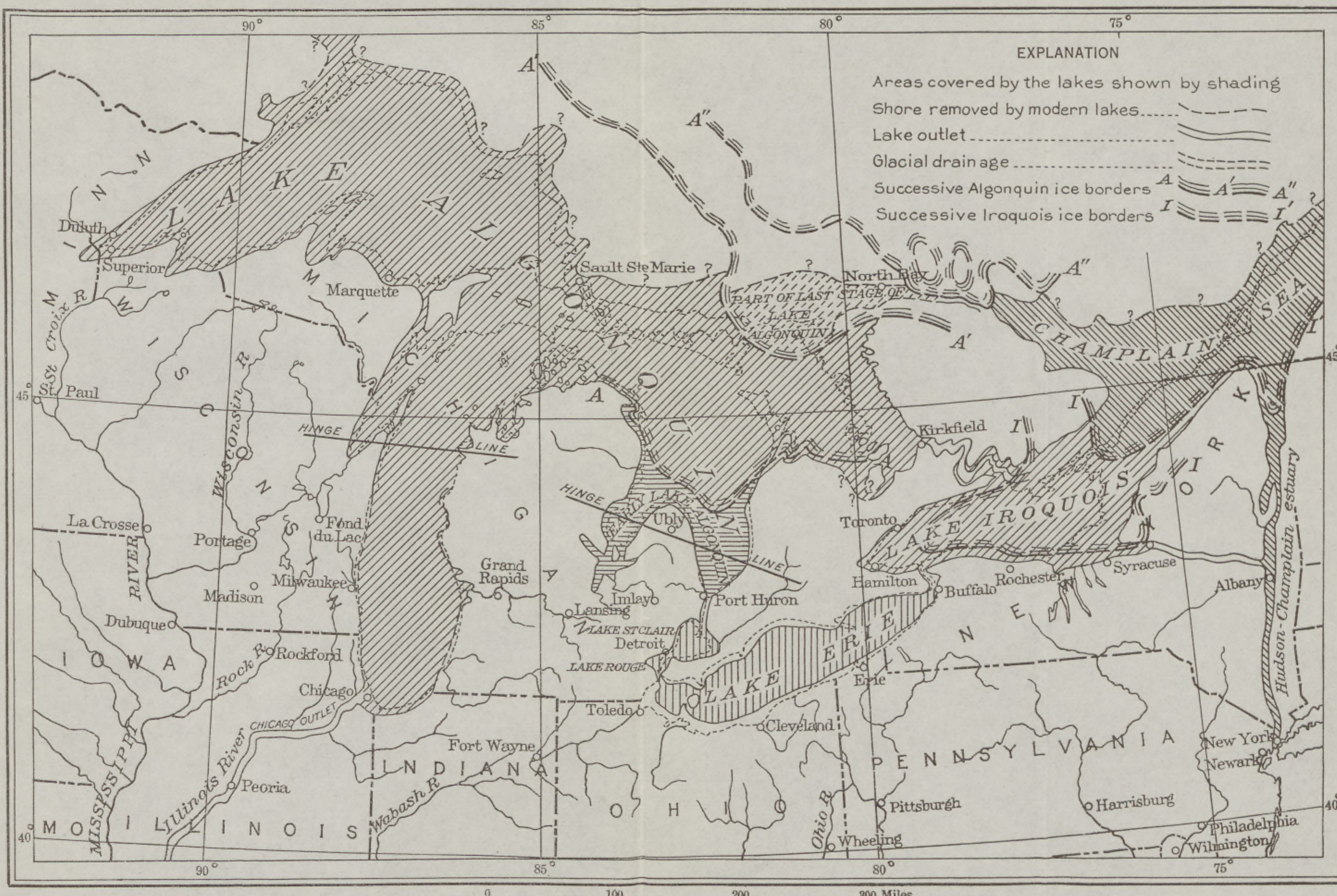
GLACIAL LAKES WARREN AND CHICAGO

By Frank B. Taylor and Frank Leverett, 1910.



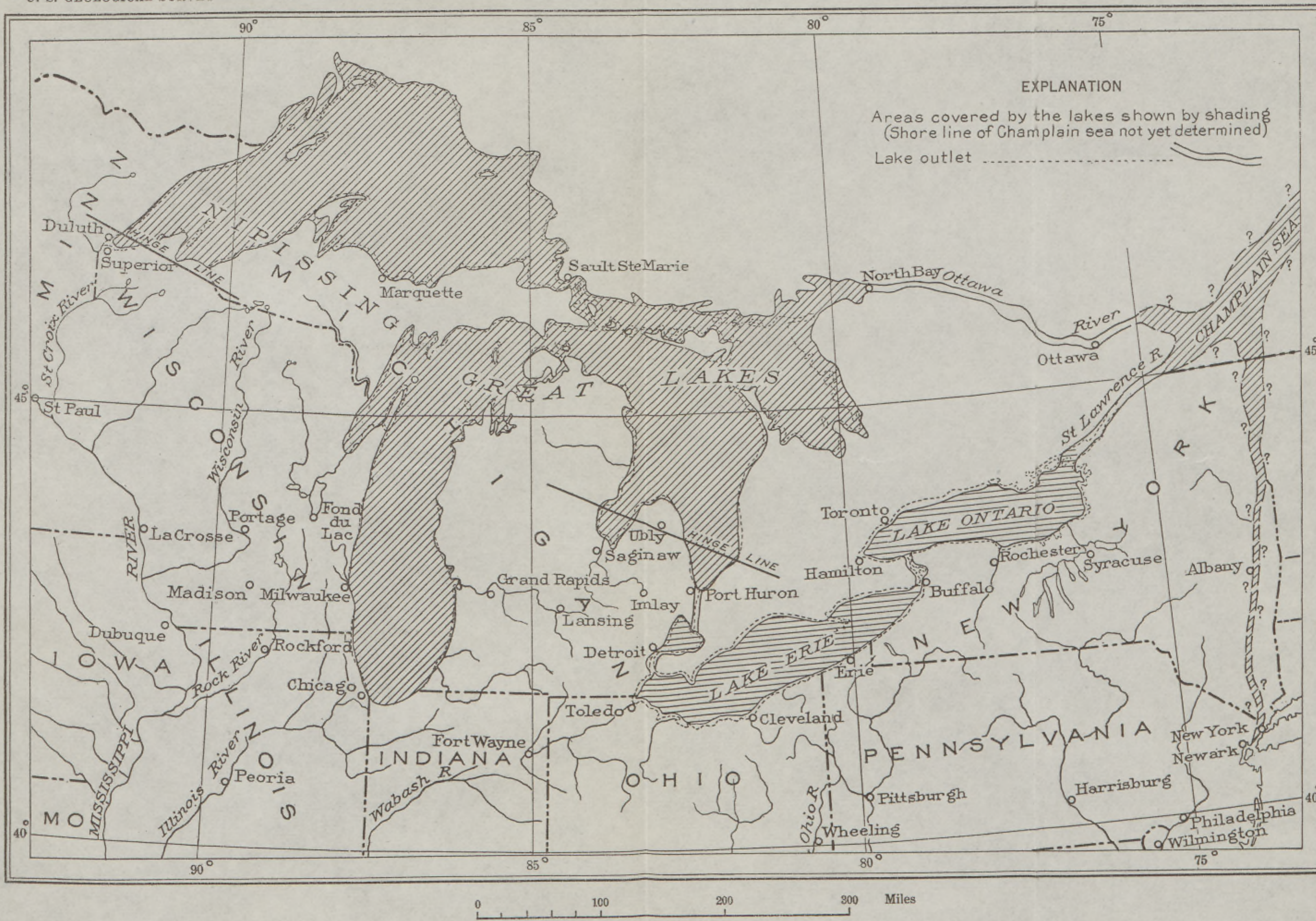

GLACIAL LAKES LUNDY, CHICAGO, AND DULUTH

By Frank B. Taylor and Frank Leverett, 1913.



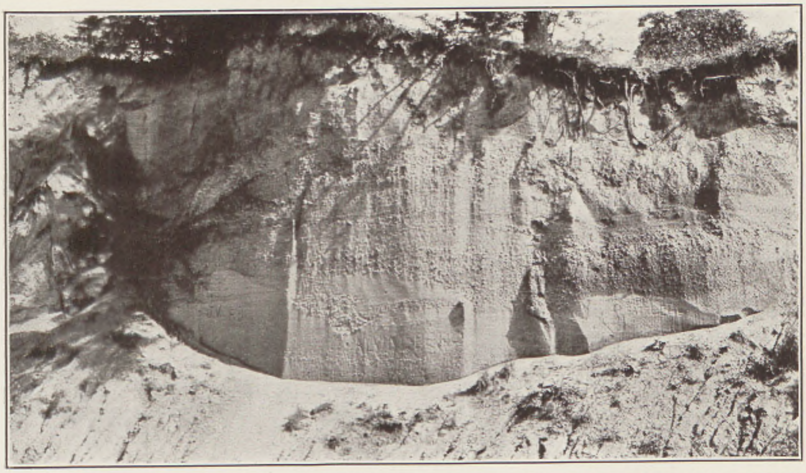

GLACIAL LAKES ALGONQUIN AND IROQUOIS, LAKE ERIE, AND CHAMPLAIN SEA

By Frank B. Taylor and Frank Leverett, 1910.




NIPISSING GREAT LAKES

By Frank B. Taylor and Frank Leverett, 1911.



*A.* COMPLEX VARIATION OF GRAVEL AND SAND IN PIT ON MILL CREEK NEAR GARFIELD PARK, CLEVELAND

The irregular bedding suggests that they were laid down underneath the ice.

*B.* VIEW LOOKING SOUTH AT THE JUNCTION OF THE EAST AND WEST BRANCHES OF THE ROCKY RIVER

The postglacial valleys of these streams shown in the view have narrow flat bottoms and are bordered by steep bluffs of Cleveland shale.


SUCCESSIVE POSITIONS OF THE ICE BORDER IN OHIO AND NEIGHBORING REGIONS

By Frank Leverett and Frank B. Taylor, 1910. Data for eastern Wisconsin from Alden and Weidman.

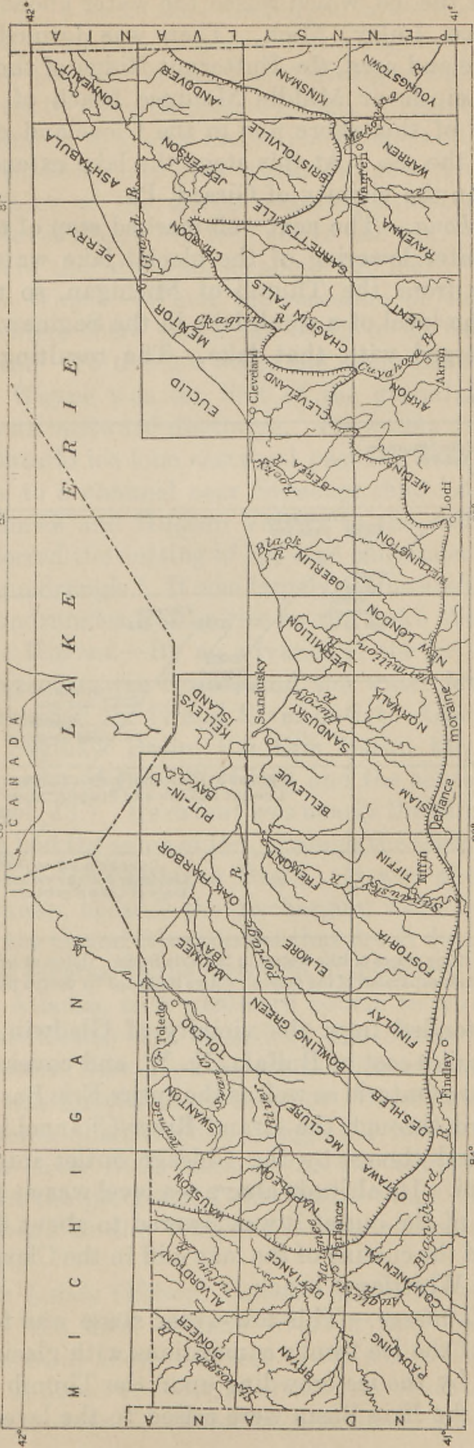



FIGURE 8.—Defiance moraine in Ohio, shown by barbed line. Names of published topographic maps shown in rectangles. (Note that from Lodi eastward this map corrects the course shown in U. S. Geol. Survey Mon. 41, pls. 13 and 15, and Mon. 53, pl. 5)

by a readvance of the ice, which raised the water about 20 feet to an outlet leading past Imlay, Mich. Then was formed the highest beach in the Cleveland area, the Butternut Ridge of the Berea quadrangle and the Leipsic or Middle Maumee beach of the Maumee Basin. The level of this shore line in the Cleveland district is 770 to 780 feet above the sea. At this stage the lake extended eastward to the ice border in the vicinity of Girard, Pa.

*Glacial Lake Arkona.*—The next well-marked step of the ice retreat caused a still greater lowering of the glacial lake waters. The ice withdrew entirely from the Thumb of Michigan, so that the lake east of it fell to the level of a small lake in the Saginaw Basin (Lake Saginaw) and merged with that lake. The resulting lake, called

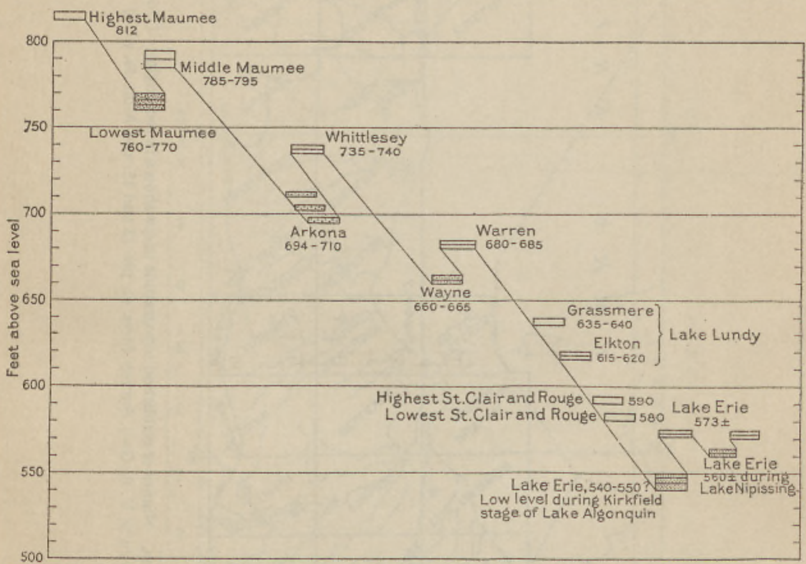



FIGURE 9.—Falling and rising stages of lake waters in the Erie Basin. Oldest at left. Beaches submerged by later expansion of the ponded waters indicated by dotted pattern

Lake Arkona, extended from the vicinity of Gladwin, Mich., to a point at least 40 miles east of Buffalo, N. Y., and covered a considerable part of southern Ontario as well as the entire Erie Basin. It found an outlet westward through the Grand River Channel into the Lake Michigan Basin and thence by the Chicago outlet into the Illinois and the Mississippi. Its altitude above sea level was at first 710 feet, but by deepening of the outlet it was lowered to about 695 feet. To this lake is referred the cutting of the lake cliff in the Cleveland district at the base of the Whittlesey beach.

*Glacial Lake Whittlesey.*—This low-water stage was followed by a notable advance of the ice front; connections with glacial Lake Saginaw were severed by the ice crowding upon the Thumb of Michigan, and the waters of the Erie Basin were raised to the level of an outlet near Ubly, Mich., whence they discharged down the Cass River, with a descent of 35 to 40 feet, to glacial Lake Saginaw, thence westward to glacial Lake Chicago in the Lake Michigan Basin, and thence to the Illinois River by an outlet near Chicago. (See pl. 12.) This stage of the lake is known as glacial Lake Whittlesey, and its shore line, the Belmore or Whittlesey beach, is marked in the Cleveland district by the Middle Ridge of the Berea quadrangle and associated littoral deposits at a level about 735 feet above the sea. The bases of the wave-cut cliffs of this stage are at about 720 feet.

*Glacial Lake Wayne.*—When the recession of the ice front again lowered the waters there was a fall of 75 to 80 feet from the Lake Whittlesey level. To this low stage the name Lake Wayne has been given. Lake Wayne was the first of the glacial lakes in the Erie Basin to have an eastward discharge. Its waters extended along the front of the Ontario ice lobe eastward past the Finger Lakes of western New York to a channel near Syracuse that discharged eastward down the Mohawk and Hudson Valleys to the Atlantic Ocean. To this lake is referred the cutting of the lake cliff under the North Ridge of the Berea quadrangle. It was largely obliterated in the Cleveland and Euclid quadrangles by the rise to the Lake Warren stage.

*Glacial Lake Warren.*—By an advance of the ice in New York the outlet near Syracuse was closed, and the water level was raised so that it again reached the Grand River outlet. Glacial Lake Warren occupied the Saginaw Basin, the Erie Basin, the intervening low areas on the border of Lake St. Clair, and the southern part of Lake Huron. (See pl. 13.) Its extent was nearly the same as that of Lake Arkona, and it had the same outlet, through the Grand River Valley to Lake Chicago, in the Michigan Basin. It was about 15 feet lower than Lake Arkona, because the discharging waters of Lake Saginaw had deepened the Grand River outlet that much during Lake Whittlesey time. The reversal in the direction of discharge from an eastward course to the Atlantic to a westward course to waters that drained to the Gulf of Mexico was caused by the advance of the Ontario ice lobe in western New York across the line of eastward discharge. At this stage was formed the Warren or Forest beach, which on the map of the Berea quadrangle is designated North Ridge. West of the Cuyahoga River little more of the Cleveland district was submerged than at the preceding Lake Wayne stage. East of the river the lake extended to the Woodland Avenue beach, about 680 feet above sea level.

*Glacial Lake Lundy* (*Elkton, Dana*).—When the waters were again lowered below the level of Lake Warren they halted first at the Grassmere beach, at about 640 feet above sea level, and later at the Elkton beach, at about 620 feet, each marking short transitional stages before the waters of the Erie Basin became finally separated from those in the Huron and Ontario Basins. (See pl. 14.) There has been little study of the beaches formed at these stages east of Michigan, partly because they are weak and difficult to identify. The outlet at both stages appears to have been eastward near Syracuse, N. Y., and thence down the Mohawk and Hudson Valleys to the Atlantic. The sandy strip along St. Clair Avenue in the Euclid quadrangle about 640 feet above sea level may represent the Grassmere beach. Only faint traces of the shore were found west of Cleveland. The Elkton beach is faintly developed in the northwestern part of the Berea quadrangle, but most of it has been cut away by the encroachment of the present Lake Erie, whose bluffs now rise above the 620-foot contour throughout much of the Cleveland area. The opening of the Mohawk outlet lowered the lake to a level below the Niagara escarpment and restricted the waters in the Erie Basin to about their present area. (See pl. 15.)

### POSTGLACIAL LAKE

*Lake Erie.*—When the ice had receded in western New York sufficiently to allow water to escape along its southern edge through the low plain between the Niagara escarpment and the shore of Lake Ontario into the Mohawk Valley, the level of the lake waters east of the Erie Basin was drawn down below the level of the Niagara escarpment, and the remaining body of water had about the extent of the present Lake Erie. The Niagara River connected the two lakes, and Niagara Falls became operative and began their recession. With the institution of these features the direct influence of the oscillating ice dam on the lake in the Erie Basin ceased, and its postglacial history began.

There has been a slight differential uplift since that time at the east end of the lake, which raised the outlet and caused the waters to extend a little farther west, but, in general, the first stage of Lake Erie was nearly of the same area and extent as the present lake. When Lake Erie became an independent body of water the ice still covered the greater part of the Lake Huron Basin and discharged its waters southward to Lake Erie along the line of the present drainage from Lake Huron to Lake Erie (pl. 15), but as the ice melted back in the Huron Basin and in the district on the east an outlet for the waters was opened, leading from a place near Kirkfield, Ontario, down the Trent River Valley into a lake in the Ontario Basin known as Lake Iroquois. By this change the Erie Basin had its drainage area much reduced, and the level of the water in it became correspondingly lower. It is estimated that its level may have been at least as low as 560 feet above the sea, or 13 feet or more lower than the present level of the lake. After a long period of eastward discharge through the Kirkfield or Trent River outlet the region through which that outlet passed was uplifted so that it could no longer carry the water from the Huron Basin. (See figs. 10 and 11.) This uplift caused the water to rise again to a sufficient height at the south end of Lake

Huron to discharge southward along the present line of drainage to Lake Erie. By this time the ice had been melted away from the Michigan and Superior Basins also, and the water from these three great lakes was turned into Lake Erie. This accession of water appears to have brought the lake up practically to its present height, 573 feet above sea level. The Erie Basin drained into the Atlantic by way of the Mohawk and Hudson Rivers. For a time after the St. Lawrence region was free of ice its altitude was below sea level,

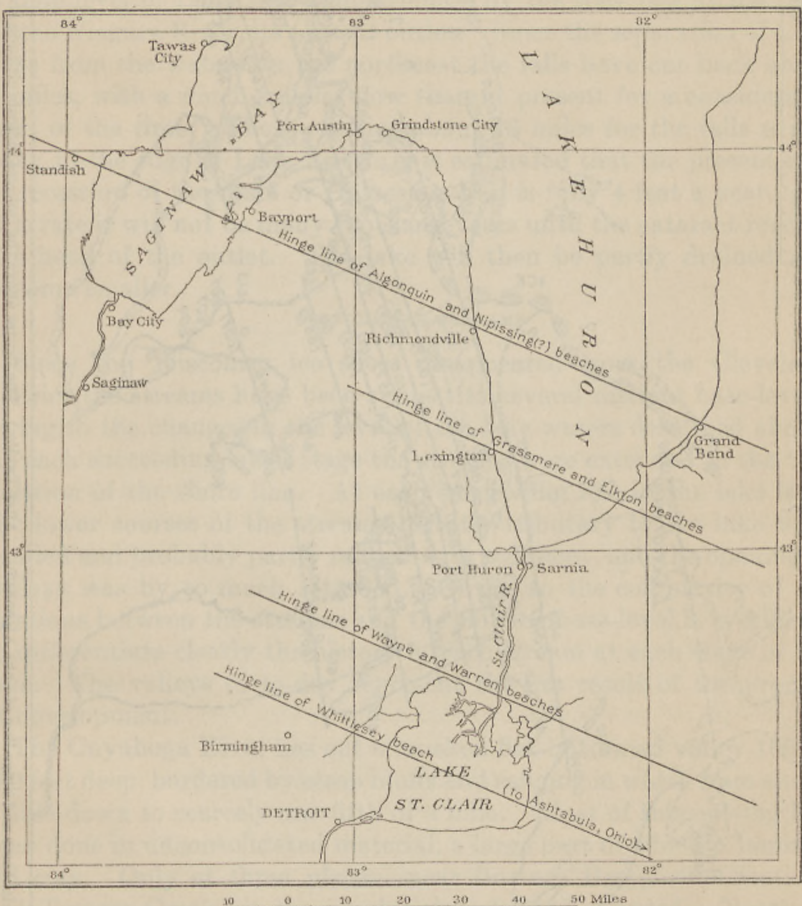



FIGURE 10.—Hinge lines of Lakes Whittlesey, Wayne, and Warren

and an arm of the ocean extended westward into the Ontario Basin. (See pl. 16.) At that time Lake Erie was again slightly lower than now, for the waters of the upper lake basins, comprising the Nipissing Great Lakes, flowed eastward from Georgian Bay by way of the Ottawa River into the St. Lawrence arm of the sea.

The Sandusky River at that time ran across what is now Sandusky Bay. The old channel is traceable through the bay, and its banks are less than 10 feet below the surface of the bay. From this evidence it appears that the level of the river at ordinary stage was probably but little more than 10 feet below the present level of Lake Erie, or

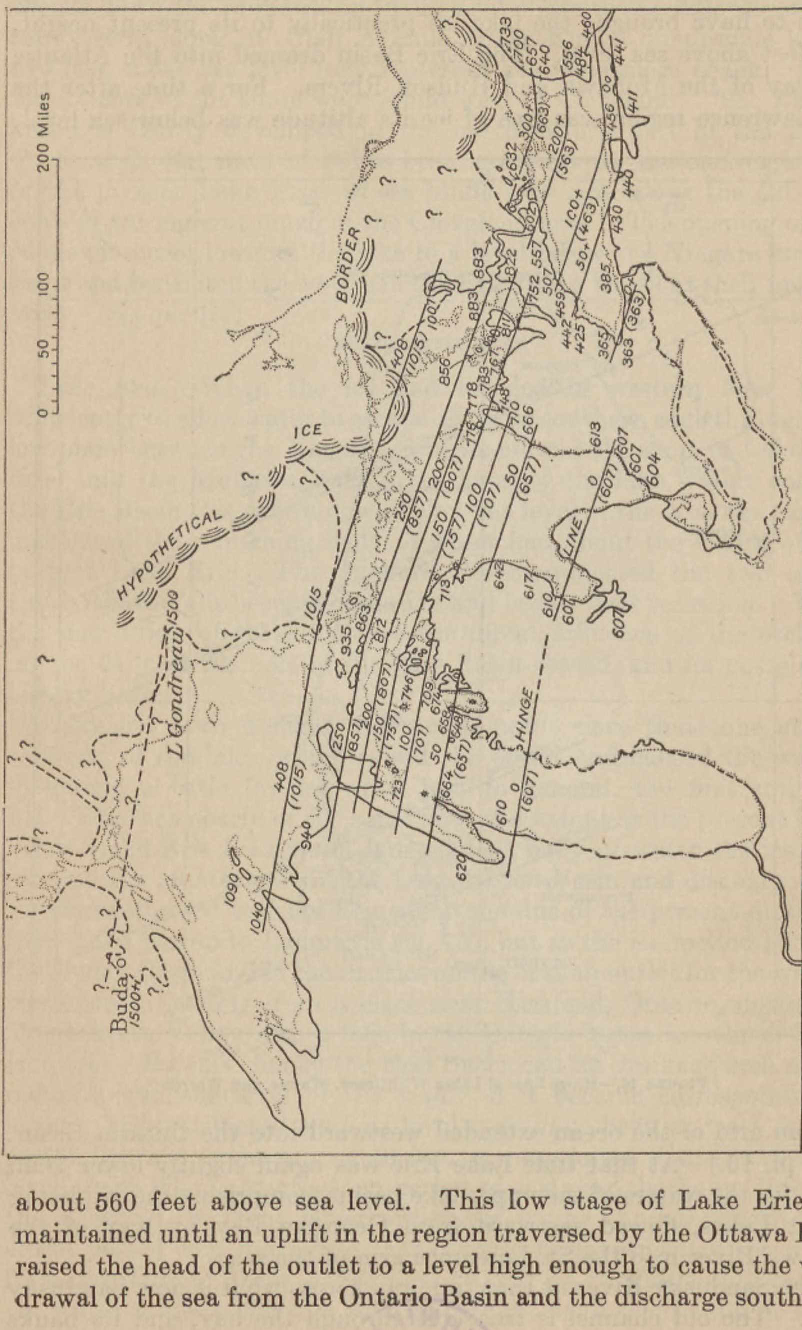



FIGURE 11.—Isobases and hinge line of Lake Algonquin. (After Taylor.) The figures above the isobases indicate altitude above the horizontal or unaffected part of the beach south of the hinge line; the figures in parentheses below the isobases and the scattered figures elsewhere indicate altitude above sea level

about 560 feet above sea level. This low stage of Lake Erie was maintained until an uplift in the region traversed by the Ottawa River raised the head of the outlet to a level high enough to cause the withdrawal of the sea from the Ontario Basin and the discharge southward into the Erie Basin from the basins of Lakes Superior, Michigan, and Huron to be resumed.

Studies of the Niagara Gorge and the rate of recession of the falls indicate that the lake has been at this higher level for less than 4,000 years.[12] The present stage of Lake Erie is thus of relatively recent date. Yet in this brief period the lake appears to have cut back its coast line in the Cleveland district more than the amount of cutting accomplished in this area by any of the glacial lakes.

The level of Lake Erie is determined by the rock bed at the head of the Niagara River, its present outlet. Since the separation of Lake Erie from the waters on the northeast the falls have cut back about 7 miles, with a much smaller flow than at present for a considerable part of the time. There remains about 18 miles for the falls to cut back to the edge of Lake Erie. It is estimated that the present rate of recession of the main or Horseshoe Fall is fully 4 feet a year. At this rate it will not be many thousand years until the cataract reaches the head of the outlet. The lake will then be partly drained and become smaller.

### POSTGLACIAL STREAMS

Since the Wisconsin ice sheet disappeared from the Cleveland district the streams have been subject to several distinct base-levels, owing to the changes in the level of the lake waters described above. At each succeeding lower stage the streams were extended to the new position of the shore line. At each succeeding rise in the lake level the lower courses of the streams directly tributary to the lake were flooded and probably partly refilled with sediment, and the opening of valleys was by so much retarded. Owing to the complexity of the relations between the streams and the shifting base-level it is difficult to differentiate clearly the history of each stream at each stage of the lake. The valleys of to-day represent the net result of the process of development.

The Cuyahoga River has cut a crooked flat-bottomed valley 100 to 180 feet deep, bordered by steep bluffs and ranging in width from about a mile down to scarcely one-fifth of a mile. Most of this cutting has been done in unconsolidated material, a large part of which is laminated clay. Only at three places—near Boston, Brecksville Station, and Tinkers Creek—is the preglacial rock bluff exposed. North of Brecksville Station the valley cuts across a projecting rock point, and there its trough is very narrow.

The Rocky River has worked mostly in shale. Except where the river follows or crosses its preglacial valley, it occupies a narrow, steep-walled channel. (See pl. 17, *B*.) Down to relatively recent

[12] U. S. Geol. Survey Geol. Atlas, Niagara folio (No. 190), 1913.

time the junction of the East and West Branches was north of two rock prominences north of the road running east from Olmsted. The channel west of these prominences, about 100 feet deep, was probably cut by the West Branch and later abandoned. The diversion through the gap at the road east of Olmsted is said to have occurred at about the time the first settlers came to this region. The diversion through the passage between the rock prominences was evidently much earlier.

The erosion on tributaries of the Cuyahoga and Rocky Rivers has been relatively slight, except in the lower courses, where they are coming into adjustment with the deep valleys of the major streams. There are usually cascades where the streams pass from sandstone to shale formations. Such cascades are conspicuous where the streams pass out of the Berea sandstone. Excavation in the rock formations has been very slight except as stated above. The drainage of the elevated upland is to a great degree rudely coincident with the preglacial lines, but on the lowlands the preglacial drainage channels have been so completely filled with drift deposits that most of the present streams follow new courses.

## ECONOMIC GEOLOGY

By Frank Robertson Van Horn

The mineral resources of the Cleveland, Berea, and Euclid quadrangles consist of clay and shale, building stone and grindstones, salt, natural gas and petroleum, sand and gravel, and road material. These substances are named in the probable order of their commercial value. Other natural resources are peat, water, and the soils.

### CLAY AND SHALE

The clay industry in Cleveland and vicinity includes the manufacture of common brick; vitrified brick, which embraces face brick, sewer brick, and paving block; and hollow ware, such as hollow brick, fireproofing, conduits, and a small quantity of draintile.

*Clay.*—The clays of the region are chiefly transported material of glacial origin. They are either yellow or blue, and the beds range in thickness from 3 to 75 feet. In one place, however, borings indicate a thickness of more than 150 feet. The blue clays are very dense and tough, and dynamite is sometimes employed in mining them. Boulders usually occur in the clays but in places are practically absent. They consist of granite, gabbro, anorthosite, gneiss, schist, and several kinds of limestone. The limestone is especially detrimental in brickmaking, as on burning any particles present are converted into lime, which will absorb moisture and cause the brick to chip off or even break into pieces. Some alluvial clay is found along the streams, but none is used for manufacturing. The nearest approach to a residual clay in the region is the so-called DeKalb clay,[13] found in a strip a quarter of a mile to a mile wide and parallel to the shore of Lake Erie from Dover Bay through Lakewood and Nottingham toward Wickliffe. It has been formed largely by the weathering of the Chagrin shale, although probably added to by wave action when Lake Erie stood at a higher level. An ultimate chemical analysis of this clay and of one of the common blue clays called "Erie clay" by Newberry follow:

*Analyses of clays from the vicinity of Cleveland*

| | 1 | 2 |
|---|---|---|
| Silica ($SiO_2$) | 62.25 | 59.70 |
| Alumina ($Al_2O_3$) | 20.35 | 14.80 |
| Iron oxide ($Fe_2O_3$) | 5.30 | 4.60 |
| Magnesia (MgO) | 1.01 | 5.14 |
| Lime (CaO) | .60 | 8.90 |
| Soda ($Na_2O$) } Potash ($K_2O$) | 2.46 | 3.40 |
| Combined water ($H_2O$) | 7.25 | 4.00 |
| Sulphur trioxide ($SO_3$) | .34 | ---------- |
| | 99.56 | 100.54 |

1. DeKalb clay (residual) from John Kline Brick Co., Wickliffe, Ohio. Analysts, F. J. Peck & Co.
2. "Erie" clay, a blue drift clay used by some of the brickmakers of this vicinity. Ohio Geol. Survey, vol. 1, p. 177, 1873. Analyst, T. G. Wormley.

Comparison of analysis 1 with that of the Chagrin shale (No. 3, p. 106) shows a great similarity save for the increase of silica in the clay, which might be expected. The DeKalb clay shows a slight loss of soluble constituents—alkalies, lime, magnesia, and iron. It is utilized only incidentally as it falls into the pit of Chagrin shale, which is used at Wickliffe for the manufacture of vitrified brick and paving block. If, however, the clay were present in sufficient quantity, it could be used for brickmaking, for which it is well adapted. The sulphur shown in the analysis comes from undecomposed pyrite concretions in the shale. Analysis 2 shows a large percentage of magnesia and lime, which probably originate in part from the limestone pebbles that generally occur in the drift.

*Shale.*—The shales of the region that are utilized for clay products are the Chagrin, Cleveland, Bedford, and Orangeville. The Chagrin shale is predominantly grayish blue; the Cleveland shale is commonly black, although some layers are dark blue; the Bedford shale is part red and part blue; and the Orangeville shale is near black, although usually not so dark as the Cleveland. Most of the shales contain concretions of pyrite, and in some beds of the Chagrin clay-ironstone

[13] Lapham, J. E., and Mooney, C. M., Soil survey of the Cleveland area, Ohio, p. 19, U. S. Dept. Agr. Bur. Soils, 1906.

concretions are very abundant. Several ultimate analyses of the shales were obtained from the brick companies and are given below.

*Analyses of shales from the vicinity of Cleveland*

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| Silica ($SiO_2$) | 58.71 | 56.40 | 57.80 | 61.20 | 61.90 | 62.60 | 59.35 | 55.13 | 60.26 | 59.85 |
| Alumina ($Al_2O_3$) | 21.90 | 23.02 | 21.11 | 19.21 | 21.55 | 21.10 | 20.05 | 19.99 | 20.57 | 18.60 |
| Iron oxide ($Fe_2O_3$) | 4.55 | 4.50 | 5.80 | 4.55 | 4.25 | 4.40 | 8.05 | 5.28 | 4.00 | 4.50 |
| Magnesia (MgO) | 2.00 | 1.64 | 1.73 | 1.46 | 1.44 | 1.40 | 1.51 | 1.33 | 1.85 | 1.40 |
| Lime (CaO) | 1.67 | .85 | .80 | 2.00 | 1.50 | 1.54 | 1.20 | .44 | .48 | .40 |
| Soda ($Na_2O$) } Potash ($K_2O$) | ------- | ------- | 2.95 | ------- | ------- | ------- | 4.11 | 3.37 | ------- | ------- |
| Combined water ($H_2O$) | 6.64 | 5.91 | 6.01 | 9.13 | 4.96 | 4.12 | 5.30 | 6.66 | 3.34 | 6.23 |
| Sulphur trioxide ($SO_3$) | 2.57 | .86 | 1.22 | .43 | .20 | 1.05 | ------- | ------- | 3.52 | 2.05 |
| Carbon (C) | .00 | .00 | .00 | .00 | .00 | .00 | .40 | 7.14 | 4.47 | 3.93 |
| | 98.04 | 93.18 | 97.42 | 97.98 | 95.80 | 96.21 | 99.97 | 99.34 | 98.49 | 96.96 |

| | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 |
|---|---|---|---|---|---|---|---|---|---|
| Silica ($SiO_2$) | 56.10 | 58.10 | 55.10 | 59.90 | 62.77 | 58.60 | 57.28 | 57.40 | 56.61 |
| Alumina ($Al_2O_3$) | 17.18 | 15.50 | 20.86 | 26.28 | 24.93 | 19.50 | 21.13 | 21.20 | 21.63 |
| Iron oxide ($Fe_2O_3$) | 4.42 | 4.22 | 4.30 | 4.35 | 4.55 | 6.05 | 8.52 | 6.57 | 7.08 |
| Magnesia (MgO) | 1.24 | 1.08 | 1.46 | 1.84 | 1.40 | 1.11 | 2.13 | 1.40 | 1.41 |
| Lime (CaO) | .15 | .05 | 1.80 | .60 | .92 | 1.10 | 5.79 | 1.00 | 1.11 |
| Soda ($Na_2O$) } Potash ($K_2O$) | 2.67 | 2.91 | -------- | -------- | -------- | 3.36 | -------- | { 4.10 | 3.51 |
| | | | | | | | | { 1.00 | .48 |
| Combined water ($H_2O$) | 6.49 | 7.02 | 7.30 | 5.40 | 4.35 | 7.08 | 5.22 | 7.75 | 6.53 |
| Moisture | -------- | -------- | -------- | -------- | -------- | -------- | -------- | -------- | 2.00 |
| Sulphur trioxide ($SO_3$) | -------- | -------- | 3.13 | 1.67 | .96 | -------- | -------- | -------- | -------- |
| Carbon (C) | 11.01 | 10.50 | 5.85 | .32 | .00 | 3.28 | -------- | -------- | -------- |
| | 99.26 | 99.38 | 99.80 | 100.36 | 99.88 | 100.08 | 100.07 | 100.42 | 100.36 |

1, 2. Chagrin shale, blue, Cleveland Brick & Clay Co. F. J. Peck & Co., analysts.
3. Chagrin shale, blue, John Kline Brick Co. F. J. Peck & Co., analysts.
4. Chagrin shale, brown, Newburg Brick & Clay Co. F. J. Peck & Co., analysts.
5, 6. Chagrin shale, blue, Newburg Brick & Clay Co. F. J. Peck & Co., analysts.
7. Chagrin shale, blue, Ohio Clay Co. Oscar Textor, analyst.
8. Cleveland shale, black, Cleveland Brick & Clay Co. Oscar Textor, analyst.
9, 10. Cleveland shale, black, Cleveland Brick & Clay Co. F. J. Peck & Co., analysts.
11, 12. Cleveland shale, black, Brower farm, Ohio Clay Co. Oscar Textor, analyst.
13. Cleveland shale, black, Newburg Brick & Clay Co. F. J. Peck & Co., analysts.
14. Green repressed paving block of the Cleveland Brick & Clay Co., made from Chagrin and Cleveland shales with very little glacial drift. F. J. Peck & Co., analysts.
15. Green repressed paving block of the Newburg Brick & Clay Co., made from Chagrin shale with a little Cleveland shale but more glacial drift. F. J. Peck & Co., analysts.
16. Average of seven samples taken in proportion to the thickness of strata from the side of a cliff consisting of Chagrin and Cleveland shales with glacial drift. Analyses made for the Ohio Clay Co. Oscar Textor, analyst.
17. Bedford shale, northern Ohio, presumably from South Park or Independence, Cuyahoga County. (Ohio Geol. Survey, vol. 7, pp. 133–134, 1893. Analyst not stated.)
18. Bedford shale, northern Ohio; same as 17 but different sample and analyst.
19. Average of 10 samples of shales, chiefly of Carboniferous age, used for making vitrified brick, block, and sewer pipe elsewhere than in the Cleveland district. (Ohio Geol. Survey, vol. 7, pp. 133–134, 1893.)

The analyses given above were made for commercial work, and the determination of certain substances only was asked for, which accounts for the fact that several constituents were not determined and that very few analyses have a total of 100 per cent. In analysis 3 the water was determined by ignition with a deduction for the sulphur, and in analyses 7, 8, 11, 12, and 16 a similar calculation was made for the carbon. Comparison of the several analyses shows a marked similarity in the composition of the three shales (Cleveland, Chagrin, and Bedford) used most in the region for brickmaking, although they are of different geologic age. This similarity, however, is to be expected, as shale represents a definite product from a definite series of geologic processes, just as sandstone does.

The silica, alumina, magnesia, and lime tend to be slightly higher in the Chagrin shale than in the Cleveland. The Cleveland is always immediately recognized by the amount of carbon present. The percentage of iron seems to be somewhat higher in the Bedford, and this might be expected because this shale is generally red. The constant amount of sulphur trioxide ($SO_3$) is due to the presence of pyrite ($FeS_2$). In analyses 7, 8, 11, 12, and 16 sulphur was certainly present and has been included with water as driven off by ignition. Analysis 19 indicates that the shales of the district conform closely to the composition of other shales used in Ohio for the same purpose. Analyses 14 and 15 show the exact composition of the mixture used in a shale brick. Analysis 14 shows by the amount of carbon present that less than 20 per cent of Cleveland shale must have been used. In the shale bank of the Cleveland Brick & Clay Co. about 3 feet of glacial drift overlies 2 to 3 feet of blue Bedford shale, beneath which is 18 to 20 feet of Cleveland shale and about 88 feet of Chagrin shale. The section used for making the brick analyzed in No. 15 consists approximately of 16 feet of drift clay, 6 feet of Cleveland shale and 113 feet of Chagrin shale. The glacial clay undoubtedly contained some quartz sand, which made it richer in silica than any of the shales. In fact, there are many gradations from clay to sand and the reverse in all the glacial deposits of the region. The 6 feet of Cleveland shale, however, was not sufficient to make any impression on the analysis, if the carbon content is taken as an indication.

### BUILDING STONE

The quarry rocks of the Cleveland district are only two—the "Euclid bluestone" and the Berea sandstone or "grit," as it is generally called.

*"Euclid bluestone."*—In the immediate vicinity of Cleveland the lowermost part of the Bedford shale is replaced by a lenticular mass of bluish-gray argillaceous sandstone which was named by Prosser the Euclid sandstone lentil. This sandstone has long been quarried under the name "Euclid bluestone." It ranges in thickness in the quarries from 20 to 30 feet, is dense and fine grained, and is much harder, stronger, and less friable than its better-known neighbor, the Berea sandstone. In general it is thinly and evenly bedded, and on that account it was at first and to a small extent is yet used for flagstone without being sawed. In one locality about 20 layers were noticed in a thickness of approximately 15 feet, and many of them ranged from 2 to 6 inches thick. The specific gravity of one specimen was found to be 2.583, hence the stone weighs about 160 pounds to the cubic foot.

The only quarries worked much are at Newburg in the Cleveland quadrangle, and at South Euclid, in the Euclid quadrangle. At Newburg are two layers having a thickness of 3¼ feet each; at South Euclid the layers reach a thickness of 5 feet. In places the bluestone contains concretions in which is a great deal of pyrite. They seem denser and harder than the surrounding rocks and are a source of detriment to the stone which becomes stained yellow or brown by the oxidation of the iron sulphide to ferrous sulphate and finally to limonite. Some of the freshly quarried stone shows no trace of the concretions, but on exposure to the weather for several months the structure becomes visible. The "Euclid bluestone" is used chiefly for flagging, but it is also largely sawed for caps, sills, and steps. Perch stone is also furnished for cellar blocks and foundations. It is reported that this stone is used for making laundry tubs after it is treated chemically to decrease absorption. A considerable quantity is crushed for concrete work, the finer screenings being employed for concrete block and mortar sand. To a small extent the stone is used in making drives and roads.

Most of the following analyses of the "Euclid bluestone" are only partial, because only certain determinations were demanded.

*Analyses of "Euclid bluestone" near Cleveland*

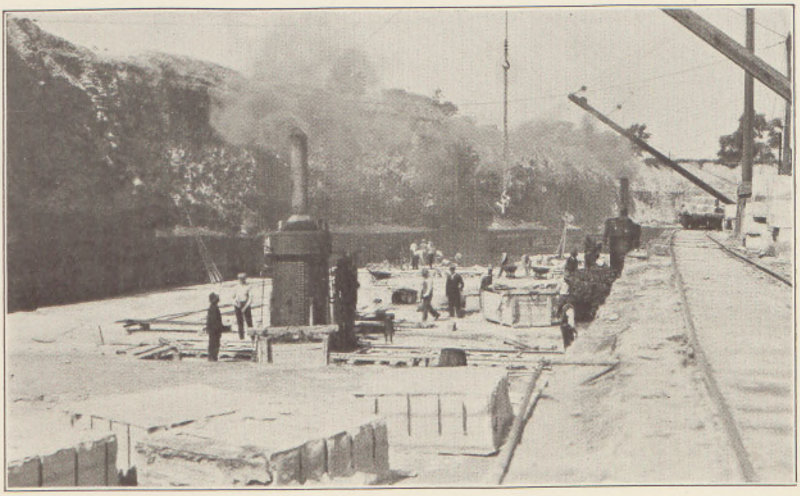
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| Silica ($SiO_2$) | 79.98 | 95.00 | 92.60 | 93.78 | 89.99 | 88.88 | 84.36 |
| Alumina ($Al_2O_3$) | 7.66 | 2.50 | 2.99 | 1.64 | .72 | .73 | .55 |
| Iron oxide ($Fe_2O_3$) | .24 | 1.00 | .72 | 2.42 | 4.28 | 6.42 | 5.71 |
| Ferrous oxide (FeO) | 2.44 | | | | | | |
| Magnesia (MgO) | 1.02 | | | | | | |
| Lime (CaO) | 1.56 | 1.50 | -------- | -------- | -------- | -------- | -------- |
| Soda ($Na_2O$) | -------- | | | | | | |
| Potash ($K_2O$) | -------- | | | | | | |
| Loss on ignition | 4.62 | | | | | | |
| | 97.52 | 100.00 | 96.31 | 97.84 | 94.99 | 96.03 | 90.62 |
| Crushing strength in pounds to the square inch | -------- | 8,000–16,000 | 10,787 | 8,640 | 11,467 | 5,219 | 12,316 |

1. Light bluish gray, Malone quarry No. 2, South Euclid. Collected by Frank R. Van Horn. Analysis made for Ohio Geological Survey in 1909 by Prof. N. W. Lord.
2. South Euclid. Analyzed by Edward Orton, sr., former State geologist.
3. South Euclid. William Pate, jr., analyst.
4–7. Light yellow, Burgess quarry, South Euclid. William Pate, jr., analyst.

The analyses show a considerable range in silica, alumina, and iron. In analysis 1, which is the most recent, the alkalies were not determined. This analysis likewise shows that most of the iron is in a ferrous state in the unaltered rock. The change to a ferric state is shown in analyses 5, 6, and 7, where the rock was stained yellow.

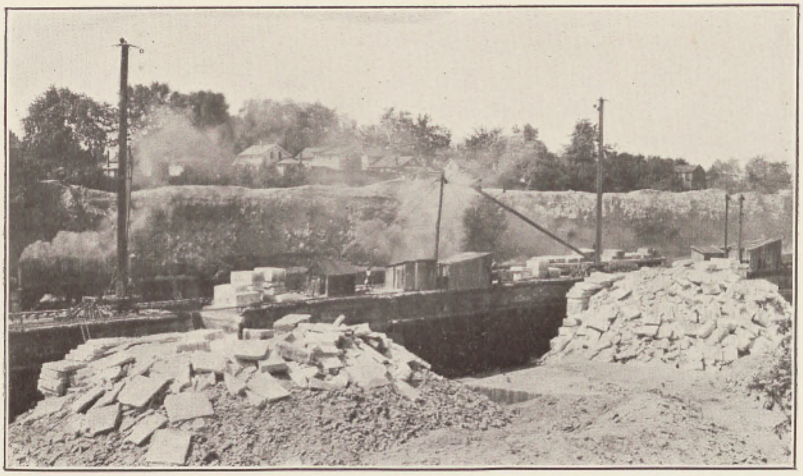
In addition to the crushing resistance given with the preceding analyses, the following results were obtained on "Euclid bluestone" from the quarry of the Caine Stone Co., Newburg, by H. D. Pallister at the Case School of Applied Science. The specimens were approximately 3-inch cubes.

*A*

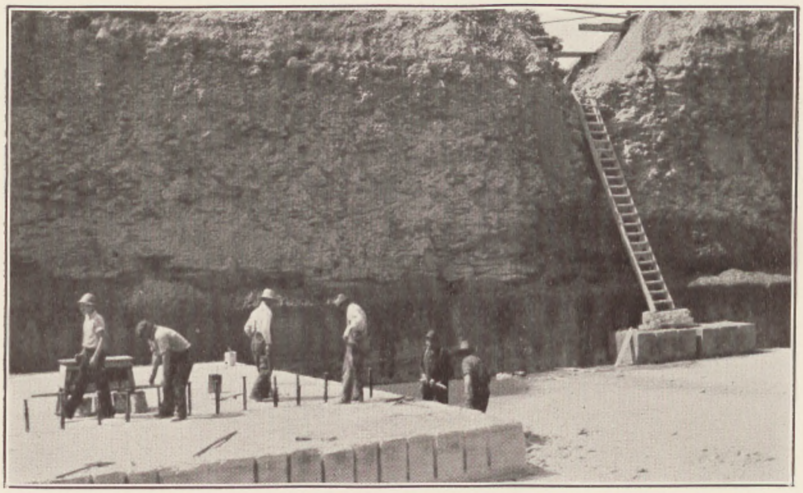


*B*

*A*, *B*. QUARRY AT BEREA, SHOWING SUNBURY SHALE OVERLYING BEREA SANDSTONE



*A.* QUARRY AT BEREA, SHOWING SUNBURY SHALE OVERLYING BEREA SANDSTONE



*B.* WEDGE AND FEATHER SYSTEM OF BREAKING SANDSTONE BLOCKS IN QUARRY AT BEREA

Shows Sunbury shale overlying more than 30 feet of Berea sandstone.

*Crushing tests on "Euclid bluestone" from quarry of Caine Stone Co., Newburg*

| | Average surface area (square inches) | Crushing load (pounds) | Pressure (pounds to the square inch) |
|---|---|---|---|
| Perpendicular to bedding | 9.1125 | 110,490 | 12,125 |
| Do | 9.4394 | 108,750 | 11,521 |
| Parallel to bedding | 9.1875 | 141,880 | 15,442 |
| Do | 9.471 | 158,540 | 16,739 |

These figures show the rather peculiar result that the rock is stronger parallel to the bedding plane than perpendicular to it. The stone, however, is very dense and is apparently massive without any trace of structure. The stone from this quarry weighs about 160 pounds to the cubic foot and has a specific gravity of 2.58.

*Berea sandstone.*—The Berea sandstone or "grit" is a medium to fine grained gray, faint yellow, or bluish-gray sandstone and is generally very evenly bedded. The yellowish or bluff colors are always found in the upper parts of the quarry, where the iron compounds have been oxidized to limonite. This sandstone is the great quarry rock of northern Ohio and ranges from 30 to 135 feet in thickness within the Cleveland district, although at Amherst, in the Oberlin quadrangle, a thickness of at least 225 feet is reached. The rock, although all commonly called Berea "grit," differs considerably in hardness, texture, and structure in the different strata. Some of the differences in structure that are perceptible to the naked eye are shown by names used by the quarrymen, such as shell rock, spider web, split rock, and liver rock. The shell rock is a cross-bedded rock that is also thinly bedded, so that it gives the appearance of a series of superposed shells. Such a layer is generally found at the top of the formation. Spider web is similar to cross-bedding, but the structure is finer and more delicate. This stone can not be used because of the irregularity of splitting, whereas split rock is one in which the bedding planes are even and close together, so that the rock may be easily split in any desired thickness. The liver rock is the opposite extreme from the split rock, and little if any structure or bedding is perceptible in it. It is, therefore, more difficult to break into dimension blocks than the split rock. Besides these noticeable differences, layers that look alike differ considerably in grain and hardness. Some are suitable for grindstone on account of the hardness of the grains and the absence of cement, which prevents glazing. Other layers are used for building stone, and still others can be employed only for bridge stone. In this rock as in the "Euclid bluestone" there is considerable pyrite that oxidizes to limonite, which stains the stone yellow to brown. The specific gravity of the rock ranges from 2.11 to 2.24, and its weight from 133 to 140 pounds to the cubic foot, depending upon the weight of water that it carries. The ratio of absorption is given as 1:16 to 1:37 with an average of 1:24.[14]

At Berea, where the largest quarries are situated (see pls. 22, 23), probably 75 acres of stone has been taken out to an average depth of 30 feet in about 50 years of operation. The quarries are not carried deeper because the split rock, the most desirable kind, does not extend below that depth. The stone is used chiefly for grindstones, curbing, block, bridge, and sawed stone, such as flagging, caps, sills, and steps. Some stone is made into moldings, cornices, columns, and carvings. Trimmings and refuse are sold for riprap and rubble, if possible. The following analyses were obtained:

*Analyses of Berea sandstone, Cleveland district*

| | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Silica ($SiO_2$) | 93.13 | 91.89 | 96.50 | 91.07 | 88.30 |
| Alumina ($Al_2O_3$) | 3.86 | 3.90 | -------- | 5.29 (Alumina and ferric oxide) | 3.52 |
| Ferric oxide ($Fe_2O_3$) | .11 | 1.50 | -------- | | -------- |
| Ferrous oxide (FeO) | .54 | -------- | -------- | -------- | 1.83 |
| Magnesia (MgO) | .25 | .29 | -------- | .04 | 1.18 |
| Lime (CaO) | .19 | .67 | 1.00 | 1.54 | 2.08 |
| Soda ($Na_2O$) | -------- | -------- | -------- | -------- | .21 |
| Potash ($K_2O$) | -------- | -------- | .50 | -------- | .50 |
| Loss on ignition | 1.43 | 1.01 | -------- | 1.85 | 2.18 |
| | 99.51 | 99.26 | 98.00 | 99.79 | 99.80 |

1. Gray, Cleveland Stone Co., quarry No. 6, Berea. Collected in 1909 by Frank R. Van Horn for th Ohio Geological Survey and analyzed by N. W. Lord.
2. Buff, between Lake Abraham and Middleburg Stone Co.'s quarry, near Berea. Crowell & Peck analysts.
3. Cleveland Stone Co., Westview quarry No. 3. Edward Orton, analyst.
4. Gray, Amherst Quarries Co., Peninsula, Ohio. Crowell & Peck, analysts.
5. Exact locality unknown. Trace of $SO_3$ and $P_2O_5$. A. W. Smith, analyst.

The analyses show in general a higher percentage of silica and a lower percentage of iron, magnesia, and lime than the "Euclid bluestone." The average of all analyses seems to show a larger amount of alumina than the bluestone. The writer is, however, inclined to put more weight on analysis 1, which was made recently on carefully selected material. It is a fairly representative analysis except for the alkalies, which were not determined. In analysis 5 the alkalies were carefully determined, and in this respect the two analyses may be used to supplement each other.

The following tests for the compressive strength of Berea sandstone were made for the Cuyahoga County engineer's office by Crowell & Murray, on 1-inch cubes:

*Compressive strength of Berea sandstone, in pounds to the square inch*

| Source of stone | Cracked at— | Crushed at— | Source of stone | Cracked at— | Crushed at— |
|---|---|---|---|---|---|
| Berea quarries | 9,817 | 10,799 | Berea quarries | 10,800 | 10,800 |
| Do | 9,326 | 10,308 | W. B. Newcomb's quarry, South Euclid | 12,762 | 12,765 |
| Do | 7,854 | 7,854 | Do | 8,835 | 9,817 |
| Do | 9,820 | 9,820 | Do | 9,817 | 10,799 |
| Do | 10,300 | 10,300 | | | |

[14] Gillmore, Q. A., Chief Eng., U. S. Army, Ann. Rept., 1875, pt. 2, p. 850.

The following tests were made at the Case School of Applied Science by R. G. Dukes on stone from the Berea quarries:

A block 3.875 by 4.2 inches was tested perpendicular to the bedding. Area of face, 16.27 square inches; crushing load, 121,610 pounds; crushing strength, 7,480 pounds to the square inch.

A block 3.81 by 4.38 inches tested parallel to bedding. Area of face, 16.7 square inches; crushing load, 101,000 pounds; crushing strength, 6,050 pounds to the square inch.

These tests show that the stone is stronger perpendicular to the bedding.

Although the only rocks that are much used in the region are the "Euclid bluestone" and Berea sandstone, glacial boulders from the till are also sometimes employed for stone work. They consist of granite, diorite, anorthosite, granitic gneiss, mica schist, quartzite, or limestone. They are used mostly for cellar blocks, foundations, and fences but have also been utilized for outside walls in fancy houses, for fireplaces, and for monumental work.

### GRINDSTONES

As generally used the word "grindstone" is applied to abrasive stones of small to medium size, and pulpstone to those of larger size. No abrasives are made from the "Euclid bluestone," and only certain layers in the Berea sandstone are used. More grindstones than pulpstones are made in the area, and probably the town of Berea produces more grindstones than any other place in the United States if not in the world.

The smaller grindstones are first sawed like flagging and then broken into squares approximately of the size desired. A square hole is cut through the middle of the stone with a sharp pick, after which the stone is placed on a horizontal shaft in a lathe and rotated. As the stone revolves an iron rod resembling a crowbar is kept pressed against the side of the stone at the proper distance from the center until the stone is partly cut through. The iron bar is then held on the opposite side of the stone until the corners are completely cut off, after which the edge is made true with the same bar. The large pulpstones are sawed and treated in the same manner, but sometimes the whole operation up to the use of the turning lathe is performed with pick and hammer in a remarkably skillful way. It is said that no machines have been constructed that can make as good grindstones with as little waste of material as can be done by hand.

### SALT

Rock salt, which occurs in the Salina formation, is reached only by drilling in the Cleveland district, as the formation does not crop out in the district. In the vicinity of Cleveland drill records show two to five beds of rock salt, 74 to 168 feet thick, lying 1,950 to 2,500 feet below the surface. Salt was first discovered in Cleveland in the Newburg district about 1886, when the Cleveland Rolling Mill Co., now the American Steel & Wire Co., was drilling for natural gas,[15] "rock salt and shale" being penetrated between 1,990 and 2,154 feet and rock salt between 2,250 and 2,300 feet. The record shows three beds, 50, 20, and 5 feet thick, in addition to the 164-foot bed just mentioned. In conformity with the usual order of precipitation from saline solutions, all the salt beds are underlain by anhydrite, which the drillers termed "shale."

The first salt plant in the region was that of the Newburg Salt Co., which was started in 1889 and was last operated by the United Salt Co. Two wells were drilled in Mill Creek Valley south of Harvard Road, and brine was also piped to the plant from the original well of the Cleveland Rolling Mill Co. The plant was operated until 1902 but was dismantled in 1905.

The plant of the Cleveland Salt Co., at the corner of Ashland Road and Central Avenue, 4 miles north of the site occupied by the Newburg Salt Co., draws its brines from four wells on the premises. The first of the following records is that of well No. 2, which was finished November 4, 1905, and the second is that cited by Bownocker[16] and called well No. 2 but now known as well No. 4. The two wells are not more than 500 feet apart. The "limestone" beneath each salt bed is probably anhydrite.

*Record of well No. 2 of the Cleveland Salt Co.*

| | Thickness (feet) | Depth (feet) | | Thickness (feet) | Depth (feet) |
|---|---|---|---|---|---|
| Glacial drift | 520 | 520 | Limestone | 10 | 1,898 |
| Shales | 480 | 1,000 | Rock salt | 64 | 1,962 |
| Limestone, chiefly | 878 | 1,878 | Limestone | 2 | 1,964 |
| Rock salt | 10 | 1,888 | | | |

*Record of well No. 4 of the Cleveland Salt Co.*

| | Thickness (feet) | Depth (feet) | | Thickness (feet) | Depth (feet) |
|---|---|---|---|---|---|
| Shales and limestones | 1,821 | 1,821 | Rock salt | 10 | 1,856 |
| Rock salt | 10 | 1,831 | Limestone | 22 | 1,878 |
| Limestone | 5 | 1,836 | Rock salt | 72 | 1,95 |
| Rock salt | 5 | 1,841 | Limestone | 2 | 1,952 |
| Limestone | 5 | 1,846 | | | |

The plant of the Union Salt Co., about 2 miles north of the Cleveland Salt Co.'s wells, at Addison Road and the New York Central Railroad, draws its brines from three wells on the property and two others a short distance away. The wells range in depth from 1,980

[15] Ohio Geol. Survey, vol. 6, p. 352, 1888.

[16] Bownocker, J. A., Ohio Geol. Survey Bull. 8, p. 36, 1906.

to 2,006.5 feet. The No. 2 well, the record of which, with interpretation, follows, has been abandoned. The No. 4 well, the record of which also is given, was drilled in 1893.

*Record of No. 2 well of the Union Salt Co., Wason Street*

| | Thickness (feet) | Depth (feet) |
|---|---|---|
| Surface and glacial drift: | | |
| Ashes | 80 | 80 |
| Blue clay | 88 | 168 |
| Chagrin and underlying Devonian shales: | | |
| Slate | 22 | 190 |
| Dark shale | 66 | 256 |
| Light shale | 116 | 372 |
| Brown shale | 100 | 472 |
| Light shale | 296 | 768 |
| Dark shale | 144 | 912 |
| Devonian and late Silurian limestones: | | |
| Hard light-colored limestone | 170 | 1,082 |
| Gray limestone | 80 | 1,162 |
| Blue limestone | 145 | 1,307 |
| White sand | 25 | 1,332 |
| Devonian and late Silurian limestones—Continued. | | |
| Limestone | 56 | 1,388 |
| Gray limestone | 69 | 1,457 |
| Sand and lime | 23 | 1,480 |
| Limestone | 60 | 1,540 |
| Dark limestone | 144 | 1,684 |
| Salina formation (Silurian): | | |
| Salt and limestone | 59 | 1,743 |
| Salt | 15 | 1,758 |
| Limestone | 5 | 1,763 |
| Salt | 71 | 1,834 |
| Limestone | 26 | 1,860 |
| Salt | 35 | 1,895 |
| Limestone | 7 | 1,902 |
| Salt | 38 | 1,940 |
| Limestone | 40 | 1,980 |

*Record of No. 4 well of the Union Salt Co., Hoyt Avenue*

| | Thickness (feet) | Depth (feet) |
|---|---|---|
| Surface and glacial drift | 267 | 267 |
| Devonian shales | 723 | 990 |
| Devonian and late Silurian limestones | 775 | 1,765 |
| Salina formation (Silurian): | | |
| Salt | 16 | 1,781 |
| Limestone | 16 | 1,797 |
| Salt | 19 | 1,816 |
| Limestone | 4 | 1,820 |
| Salina formation (Silurian)—Continued. | | |
| Salt | 59 | 1,879 |
| Limestone | 21 | 1,900 |
| Salt | 37 | 1,937 |
| Limestone | 4 | 1,941 |
| Salt | 37 | 1,978 |
| Slate | 16 | [a] 1,994 |

[a] Total depth by steel-line measurement, 2,006.5 feet.

The No. 2 well penetrates a total of 159 feet of rock salt, if the 59 feet of mixed salt and limestone is omitted. The No. 4 well penetrates a total of 168 feet of salt, which, however, includes some of the strata omitted from the estimate for the No. 2 well. Though comparison of the records indicates a difference in the thickness and possibly in the number of salt beds within a distance of only a few hundred feet, part of the apparent discrepancies are doubtless due to imperfections in the driller's records. Comparison of these records with those of the wells of the Cleveland Salt Co. reveals similar apparent differences in composition and thickness of the beds at the distance of 2 miles that separates the plants. The No. 4 well of the Union Salt Co. is plugged at the bottom of the 59-foot bed of salt. The Cleveland Salt Co. stops drilling at the bottom of the first thick bed, which has a thickness of 64 to 72 feet. At the site of the Union Salt Co. this bed is 59 to 71 feet thick. Evidently there is about 74 feet of salt that is not tapped by the wells of the Cleveland Salt Co.

The salt is raised by pumping into the wells fresh water, which becomes a saturated artificial brine and is forced to the surface by additional pumping. Commercial grades of salt are manufactured at Cleveland from the artificial brine by both the vacuum-pan and the grainer process. Dairy and table salt are made, but the largest part of the product is made by the vacuum-pan method and is sold as No. 1 common fine, which is shipped loose and is loaded on cars direct from the curing floor.

## NATURAL GAS AND PETROLEUM

Two general modes of occurrence of natural gas are usually distinguished. Gas is found in shale and is called shale gas; it occurs also in sandstone, conglomerate, and dolomitic limestone, and this is known as rock gas. Both types are recognizable in the Cleveland district, and a third type is also present, which might be called drift gas.

### DRIFT GAS

The drift gas is the least abundant in the area and exists only in pockets in glacial clay or in layers of sand and gravel that lie between beds of such clay. Possible sources of this gas are the decomposition of organic matter either in the glacial drift or in the Cleveland and underlying Devonian shales, from which it may ascend into the drift. At least three occurrences of drift gas can be mentioned. One is in well No. 4 of the Union Salt Co., at Addison Road and the New York Central Railroad, where there is 267 feet of drift. A flow of gas of considerable volume was reported at 150 feet, and flows of lesser volume were obtained at 242 and 306 feet. The two higher flows were in drift, and the third was found 39 feet down in the Cleveland and underlying Devonian shales. The second occurrence is in well No. 2 of the Cleveland Salt Co., at Ashland Road and Central Avenue SE., which penetrated 520 feet of drift. At 445 feet gas was encountered in sufficient quantity to lift the drilling tools and prevent further drilling for a short time. A second well was driven alongside the salt tube to tap the gas supply, which, however, was soon exhausted. Layers of sand and gravel in the drift undoubtedly served as the reservoir for the gas tapped by these wells. A third occurrence of drift gas was found on the property of the late Thomas H. White, 8218 Euclid Avenue, Cleveland, where a shale-gas well that is still in use was driven about 1890. At a depth of 125 feet a pocket of drift gas was encountered, which blew boulders out of the well. A second pipe was put down beside the shale-gas pipe, and the gas supply thus obtained was sufficient for lighting, cooking, and heating for two years.

SHALE GAS

Shale gas ranks second in value in this district, but it is used more on a small scale by individuals than in industry. On account of one of its characteristic features shale gas is sometimes called low-pressure gas. Other characteristics are that the pressure is variable; the volume is small; the occurrence is not limited to any definite horizon and in many places is independent of oil; and the flow is likely to persist for a long time and is not dependent to any great extent on the structure of the rocks. Several hundred gas wells in the Cleveland district draw their supply from the shales, which have a thickness of about 1,250 feet. The wells range in depth from 400 to 1,840 feet, but most of them are completed at about 800 feet. This practice indicates that all the wells pass through the Cleveland and Chagrin shales into the shale of Portage age, which has commonly been called Huron shale. Although the shale of Portage age seems to be the chief source, it is known that the entire thickness of the Chagrin and Cleveland shales contains small quantities of oil and gas. Lord [17] states that the black shales contain one-fifth of 1 per cent of petroleum and that an average thickness of 1,000 feet of shale would contain more than 10,000,000 barrels of petroleum to the square mile. However, the oil is present in such minute quantities and is so widely distributed that it can not be profitably extracted. It is possible that this oil by decomposition forms the gas and that the gas, being more volatile than oil, is able to work its way along bedding planes, cracks, joint planes, and pores, in which it finally accumulates in small quantities when further migration is arrested.

The flow from a single shale-gas well is commonly ample to furnish light for one or more houses for a long period. Some wells furnish sufficient gas for light the entire year and for fuel in the summer, and a few supply enough for light and heat throughout the year. Pressures in the region range from 3 to 135 pounds to the square inch, the high limit, however, being exceptional. A well is considered good if the initial pressure is above 50 pounds and if it produces 50,000 cubic feet of gas daily. The daily open flow is generally less than 20,000 cubic feet, but the wells are comparatively long lived, some of them producing for 20 years or more. Near Lake Erie, especially west of the Cuyahoga River, a well driven to a depth of 800 feet is generally successful in finding gas. The writer's list of wells shows that more lie west of the Cuyahoga than east of it, especially along the lake. Near Berea many farmers have one or more wells, which furnish light and in some places heat. In that neighborhood the writer knows of no unsuccessful wells, but in Parma and Brecksville Townships several wells ranging in depth from 800 to

[17] Lord, N. W., Ohio Geol. Survey, vol. 6, p. 413, 1888.

1,329 feet were drilled without striking gas. In the southern townships east of the Cuyahoga River, including Bedford, Northfield, and Boston, there are also successful wells about 800 feet deep. In the southern tier of townships west of the Cuyahoga River, however, including Columbia, Strongsville, Royalton, Brecksville, and the northern townships of Medina and Summit Counties, the number of gas wells is much smaller. The wells are also much deeper, owing to the southeasterly dip of the rocks, some being 1,200 to 1,300 feet deep, and gas is not always obtained. Royalton Township has two successful wells that are only 228 and 397 feet deep. The shallower well yields sufficient gas to light and heat one house all the year. It is believed that the gas originates in the Meadville or the Orangeville shale, or possibly in the Berea sandstone, rather than in the Cleveland and underlying Devonian shales.

The oldest shale-gas well in the Berea quadrangle, if not in the district, is in Rockport Township and was drilled in 1883 for H. A. Mastick.[18] This well, which is still in use, is 527 feet deep and when opened yielded 21,643 cubic feet of gas daily.

### ROCK GAS

Rock gas is generally a high-pressure gas and occurs in large volume at a definite horizon. Oil may or may not be associated with rock gas, and in most regions in which it is found the geologic structure is of great significance. Gas of this type occurs in all large fields, such as those of West Virginia, which have been furnishing the entire supply for Cleveland until the recent discovery of local gas at great depths in commercial amounts. In the Cleveland district rock gas, which is deep seated, was first developed about 1912 and is the most valuable natural gas in the region.

#### HISTORICAL NOTES

The oldest well in the district that produces rock gas was drilled in 1886, in Newburg, for the corporation then known as the Cleveland Rolling Mill Co. It has already been mentioned in the section on salt. This well was 3,000 feet deep and was thought to have reached the Trenton horizon. Two "sands" showing small amounts of oil were recorded in the Niagara limestone at depths of 2,658 and 2,686 feet. This is about the horizon of the so-called Newburg sand, which recent drilling operations have proved to be of some value as a source of gas and oil. The rock pressure was reported to be 400 to 500 pounds to the square inch, but the volume was only 14,000 to 16,000 cubic feet daily.

The discovery of gas and oil in Clinton (?) rocks in central Ohio between 1900 and 1907 proved an incentive to the continuation of

[18] Ohio Geol. Survey, vol. 6, p. 432, 1888.

prospecting northward, and as a result several thousand acres west of Kamms and Berea was leased for gas and oil rights between 1905 and 1907 by the East Ohio Gas Co. and the Logan Gas & Fuel Co. The former company did most of the drilling and was still at work in 1908. It also purchased the site of the Newburg Salt Co. in Mill Creek Valley, and in 1907 and 1908 it deepened the old salt wells to the horizon of the Clinton (?) beds, which are now generally considered to be older than the true Clinton of New York. In most places the wells were unsuccessful, and few of them were even capped. One of these wells was fairly successful, however, and furnished the second example of deep-seated reservoir gas in the district. This well was drilled by the East Ohio Gas Co. at North Ridgeville, Lorain County, and was finished in June, 1908. It was sold to A. L. Mills, who furnished the drillers' record, which has been interpreted as follows:

*Partial record of well drilled in June, 1908, at North Ridgeville*

| | Thickness (feet) | Depth (feet) |
|---|---|---|
| Drift | 18 | 18 |
| Bedford, Cleveland, and Chagrin shales and underlying shale of Portage age | 1,032 | 1,050 |
| Devonian and late Silurian (Cayugan) limestones (water in limestone at 1,300 feet) | 563 | 1,613 |
| Salina formation (upper part) | 80 | 1,693 |
| Salina (?), Niagara, and older (?) limestone (show of oil at 2,200 feet; water in limestone at 2,250 feet) | 825 | 2,518 |
| Clinton sand | 8 | 2,526 |
| Basal part of Albion (?) sandstone | 44 | 2,570 |
| Queenston (?) shale | 47 | 2,617 |

At the time of casing the rock pressure was 840 pounds to the square inch, and the open flow of gas was reported to be 250,000 cubic feet a day. The supply from this well was used to light and heat several houses. The "show of oil" at 2,200 feet is undoubtedly at the horizon of the Newburg sand of present operations.

The next development in deep drilling for gas in this district, so far as the writer knows, was on October 17, 1911, when the Newburg Brick & Clay Co., near Warner and Canal Roads, South Newburg, "brought in" a gas and oil well at a depth of 2,520 feet. It was found in a "sand" between limestones of Niagara age, and this bed has since been called the Newburg sand. The well was still yielding both gas and oil in December, 1915.

Two wells were finished to the so-called Clinton sand, at a depth of 2,740 feet, in February, 1912, by the National Carbon Co. and the Winton Motor Carriage Co., near Highland Avenue, Berea Road, and the New York Central Railroad. Both wells yielded about 1,000,000 cubic feet of gas daily, and the pressure was about 1,100 pounds to the square inch. There was little drilling from that time until late in 1913, when several good wells were drilled in Lakewood. Early in 1914 several other successful wells were drilled in Lakewood and

West Park, but no actual boom started until January 30, 1914. On this date, at the plant of the J. L. & H. Stadler Rendering & Fertilizer Co., South Brooklyn, gas was found at about 2,400 feet in the Newburg sand. The initial flow of the well was about 12,000,000 cubic feet, and the rock pressure was 950 pounds to the square inch. The production dropped to about 3,000,000 cubic feet within six months, and when the service from this well was discontinued in August, 1915, the pressure was only about 100 pounds to the square inch. In April, 1914, there were already 55 producing wells, 10 of which were in the Newburg and the rest in the so-called Clinton sand. Drillers came from all parts of the country, and many persons inside the western limits of the city of Cleveland as well as in Lakewood and West Park insisted on having private wells in their own back yards. As a result of this demand drill holes were placed too near together, and the production of the older wells rapidly decreased. There did not seem to be very much decrease in the initial pressure and flow of the newer wells when compared with the earlier ones, but there was a notable decrease in the life of the newer wells.

The average life of the wells of the district is said by an official of the East Ohio Gas Co. to be about eight months; other records show that some wells lasted 12 to 15 months.

The record well of the Cleveland area is stated to be the Swift well, in the Newburg sand at Walworth Avenue and West Twenty-fifth Street, which had an initial flow of 13,500,000 cubic feet.

### PRODUCING SANDS

The chief sands of economic importance have been called the Newburg and Clinton, and of these the Clinton has produced most of the gas in the Cleveland district. Some persons have applied the name Stadler sand to the Newburg, but the term "Newburg" has priority as well as more common usage. There is also one unimportant sand called the Stray sand, and the so-called Trenton lime (Trenton? limestone) has been prospected to a slight extent. (See pl. 19.)

*Stray sand.*—The Stray sand has been found in at least three places in Lakewood, at depths ranging from 1,355 to 1,400 feet, and its position must therefore be in the Devonian or the upper Silurian limestones The sand is about 3 feet thick and at two places produced oil. At the other place an initial flow of 4,000,000 cubic feet of gas was obtained. Water caused more or less trouble, and after a time the wells were abandoned or were deepened to the Clinton sand.

*Newburg or Stadler sand.*—The horizon of the Newburg or Stadler sand is found at depths ranging from 2,300 to 2,600 feet. In some places the Newburg is said to attain a thickness of 30 feet, but in others it is apparently absent. In the Lakewood district its thickness is rarely greater than 15 feet, but it becomes thicker to the south and east, toward the Denison-Harvard district, where the maximum thickness is found. In that vicinity its depth below the surface also increases, owing to the southeast dip. According to reports made by the East Ohio Gas Co., the Newburg ranges from 3 to 17 feet in thickness. At the pioneer well of the Newburg Brick & Clay Co. the sand was penetrated to a depth of 15 feet, a total depth of 2,520 feet being reached. The gas sand from this well was grayish, soft, and brittle and showed abundant cleavage planes. In polarized light even the smallest fragments showed high interference colors, which characterize certain minerals of very high double refraction. This sand dissolved almost wholly in cold dilute hydrochloric acid, and the solution showed little if any trace of iron. The properties noted previously are those of a fairly pure limestone, composed of calcite or dolomite. Another specimen of Newburg sand was grayish red and contained grayish, reddish-brown, and grayish-black particles, so that it might have been a mixture of three rocks. This sand was easily crushed, but some of the particles were hard enough to scratch glass. The grayish particles showed high double refraction and dissolved readily in cold dilute hydrochloric acid. The reddish-brown particles dissolved less readily, and the other particles were insoluble; the solution was colored yellow with iron chloride. This sand was calcareous but certainly originated from a more impure limestone than that obtained from the Newburg Brick & Clay Co.'s well.

The Newburg sand is therefore a calcareous or dolomitic limestone, more or less pure, and not a quartzose sandstone like the Clinton sand. It probably consists of a porous limestone similar to the Trenton (?) limestone of the Findlay-Fostoria region. The Newburg sand occurs in what is called the Big lime and belongs to the Niagara epoch of the Silurian. The horizon probably corresponds to that of the Lockport dolomite. Some of the wells that have been drilled to this sand without finding gas were continued down to the Clinton sand. Chemically the gas from the Newburg sand is said to be little if any different from the Clinton gas, an analysis of which is given on page 121. The Newburg has been most successfully prospected in the southern and southwestern parts of Cleveland, known as Newburg and Brooklyn, especially in what is called the Denison-Harvard district, where the sand is thickest. One of the largest wells to produce gas from the Newburg sand was the Stadler well, at Denison Avenue and the Belt Line, which really started the gas boom in the Cleveland territory. Although this well came in with 12,500,000 cubic feet of gas, at a rock pressure of 950 pounds to the square inch, it lasted only from January 30, 1914, to about August, 1915. Because of the general interest in this well, its log as given by the drillers, with a geologic interpretation, is appended.

*Log of Stadler well, Denison Avenue and Belt Line, Cleveland*

| | Depth (feet) | Formation | Thickness (feet) |
|---|---|---|---|
| Drive pipe | 70 | Drift | 70 |
| Shale | 70–1,106 | Devonian | 1,036 |
| Top of lime | 1,106 | | |
| Lime, very hard | 1,360 | | |
| Water (filled to top of hole) | 1,395 | Devonian and late Silurian (Cayugan) limestones | 689 |
| Gas | 1,415 | | |
| Through lime | 1,555 | | |
| Broken lime | 1,555–1,725 | | |
| Salt | 1,725–1,915 | | |
| Lime | 1,915–2,010 | | |
| Salt | 2,010–2,025 | Salina formation | 390 |
| Slate | 2,025 2,070 | | |
| Lime shell | 2,070–2,080 | | |
| Slate | 2,080–2,115 | | |
| Lime | 2,115–2,250 | | |
| Lime, very hard | 2,250–2,260 | Niagara limestone above Newburg sand | 240 |
| Lime, broken | 2,260–2,355 | | |
| Gas | 2,365 | Newburg sand | 20 |
| Total depth | 2,375 | | |

*Clinton sand.*—Although the sand that occurs from 75 to 150 feet below the Niagara limestone has long been known as the Clinton sand, it very certainly does not belong to the true Clinton formation but to the older beds here called Albion (?) sandstone, which, like the Newburg, are of Silurian age. On account of the common use of the term "Clinton," however, it is here used for the convenience of students of the economic geology of the region. The sand is found at depths ranging from 2,700 to 2,900 feet. In the northern part of the Cleveland district it is reached constantly at a depth of about 2,750 feet, but toward the south and east the depth increases, owing to the dip of the rocks in those directions. According to reports, its thickness ranges from 5 to 50 feet. The East Ohio Gas Co. gives figures ranging from 5 to 35 feet. At the plant of the Cuyahoga Brick & Shale Co. in Parma Township, between Ridge and Pearl Roads, the top and bottom of the Clinton sand were reported at 2,823 and 2,867 feet, respectively, giving a thickness of 44 feet. The Twin City Oil & Gas Co., at West One Hundredth Street near Bertha Avenue, drilled from 2,737 to 2,765 feet in the Clinton, a distance of 28 feet, but reported that "the Clinton here is 50 feet deep, which is about double the normal thickness." The thickness most commonly given is about 20 feet. J. C. Gillette, of the National Carbon Co., states that one of the reasons for differing reports is that some drillers include in the Clinton certain rocks that do not belong there. In his experience he finds, on approaching the Clinton, first a layer of reddish clayey sand, ranging from a mere film to 12 feet in thickness, which contains some gas. Below this sand lies 3 feet of shale, and then comes about 20 feet of gray, faint pink, or whitish sand, which is the chief gas reservoir. If these three strata were all included as Clinton, they would make up a thickness approaching 35 feet.

Two specimens of pink and gray or white Clinton sands have been investigated. They consist of quartz sand stained more or less with iron oxide, which even in the white sand dissolves in cold dilute hydrochloric acid and stains the solution yellow with ferric chloride. Neither sample showed any traces of lime, and the white sand originated from a grayish porous, friable quartzose sandstone, particles of which could be seen in the sand and were hard enough to scratch glass. Two other specimens of grayish color were examined, but these contained limestone fragments along with the sandstone and consequently effervesced easily with acid. The limestone particles undoubtedly came from horizons above the sand. Although the Clinton sand is generally porous, it is sometimes reported as very dense and hard, so as to require shooting in order to open up the flow of gas. The two following analyses were furnished by the East Ohio Gas Co.

*Analyses of natural gas from Cleveland and West Virginia*

| | 1 | 2 |
|---|---|---|
| Carbon dioxide | 0.0 | 0.2 |
| Illuminant (heavy hydrocarbons) | .2 | .3 |
| Oxygen | .1 | .15 |
| Carbon monoxide | .6 | .5 |
| Methane | 95.5 | 93.6 |
| Hydrogen | 1.6 | 1.65 |
| Nitrogen | 2.0 | 3.6 |
| | 100.0 | 100.0 |
| Average British thermal units | 1,105 | 1,095 |

1. Clinton gas.
2. West Virginia gas used in Cleveland, for comparison.

Several hundred wells have been drilled to the Clinton sand, about a fourth of which have been dry or gave so little gas that their production was not utilized. A comparatively small number of wells have yielded an initial flow of 10,000,000 cubic feet or more each, and a few of these started, according to reports, with about 13,000,000 or 14,000,000 cubic feet daily. Like most wells in the Newburg sand, many Clinton wells have declined rapidly in production. The record of a well in the Clinton sand as given by the drillers, with an interpretation, follows:

*Log of Winton Gas Engine Co.'s well, West One Hundred and Sixth Street, between Madison and Western Avenues, Lakewood*

| | Depth (feet) | Formation | Thickness (feet) |
|---|---|---|---|
| 8¼-inch casing | 60 | Drift | 60 |
| Top of lime | 1,140 | Devonian shale | 1,080 |
| Water | 1,450 | Limestone of Devonian and late Silurian (Cayugan) age | 510 |
| 6⅝-inch casing | 1,650 | | |
| Salt | 1,750–1,850 | Salina formation | 200 |
| Lime | 1,850–2,590 | Niagara limestone | 830 |
| Slate | 2,590–2,660 | | |
| Top of little lime | 2,660 | | |
| Through little lime | 2,660–2,680 | | |
| Slate | 2,680–2,704 | Albion (?) and Queenston (?) formations | 69 |
| Top of Clinton sand | 2,704 | | |
| Gas | 2,704–2,706 | | |
| Through sand | 2,706–2,713 | | |
| Red sand | 2,713–2,721 | | |
| Slate | 2,721–2,749 | | |

*Trenton (?) limestone.*—Because of the importance as a source of gas and oil in western Ohio of the Ordovician limestone that is commonly called Trenton limestone two wells have been drilled to that formation in the Cleveland district. They were both put down in the eastern part of Cleveland, and both were unsuccessful. One was drilled by the Park Drop Forge Co. at East Seventy-ninth Street and the New York Central Railroad, and the other by the Cleveland Twist Drill Co. at Lakeside Avenue and East Forty-ninth Street. In the latter well a small flow of gas was found in the so-called Trenton, and the highest rock pressure observed was only 37 pounds to the square inch. An analysis of this gas, furnished by Mr. J. V. Emmons, follows:

*Analysis of natural gas from Trenton (?) limestone at Cleveland*

| | |
|---|---|
| Carbon dioxide | 1.4 |
| Heavy hydrocarbons (illuminant) | .8 |
| Oxygen | .4 |
| Carbon monoxide | .6 |
| Methane | 95.7 |
| Hydrogen | .0 |
| Nitrogen | 1.1 |
| | 100.0 |

A condensed record from this well, in which the top of the Trenton (?) limestone was reached at 4,445 feet, follows:

*Partial record of well of Cleveland Twist Drill Co., Lakeside Avenue and East Forty-ninth Street, Cleveland*

| | Thickness (feet) | Depth (feet) |
|---|---|---|
| Drift | 200 | 200 |
| Devonian shale | 760 | 960 |
| Devonian and late Silurian limestones (Big lime) | 1,722 | 2,682 |
| Silurian limestone and shale | 102 | 2,784 |
| Clinton sand (no gas) | 36 | 2,820 |
| Shale and sandstone (Queenston ?) | 360 | 3,180 |
| Ordovician shale and limestone | 1,265 | 4,445 |
| Trenton (?) limestone | 132+ | 4,557 |

*Pressures.*—The largest authentic rock pressure reported in the Cleveland district was in a well of the National Carbon Co., which registered 1,120 pounds to the square inch. One of 1,250 pounds was reported, but it was probably not authentic. The usual initial pressure for wells in the Lakewood area was about 1,100 pounds. In the West Park area the initial pressures were about 1,000 pounds. The Stadler well decreased from 950 to 100 pounds during its period of service of about a year and a half.

PETROLEUM

Although there are vast amounts of petroleum in the Devonian shales, it is disseminated through them in such small quantities that it is not obtainable economically. At many places in the district are so-called oil springs. The "Euclid bluestone" at some localities contains a little oil, which comes to the surface along cracks and bedding planes. The oil, however, probably originates in the shales immediately underneath. The Mills well, cited in the discussion of rock gas (p. 117), showed oil at 2,200 feet, at a position in the Niagara limestone of the Big lime. This is probably the horizon of the Newburg sand. Several wells that were drilled and abandoned by the East Ohio Gas Co. in 1907 and 1908 were left uncapped, and oil either flows out at the top or can be obtained at a depth of a few feet, where it probably floats on water. During the gas boom, in 1914 and 1915, about 30 wells are reported to have found showings of oil. Two of these wells found oil in the Stray sand at a depth of about 1,400 feet, four in the Newburg sand, and the remainder in the Clinton sand. Several wells were reported to flow 30 to 40 barrels daily, some before and some after shooting, but most wells came in at 10 to 20 barrels, and practically all were short lived. Most of the wells of the Cleveland field after producing a few barrels for a month or so have ceased pumping. It is therefore evident that any hope of an oil boom in the Cleveland district was disappointed. Probably the best oil well is that of the Newburg Brick & Clay Co., which was the real pioneer of the district. (See p. 117.) This gas and oil well came in on October 17, 1911, with a natural flow of 35 to 40 barrels. After it was shot it produced 100 barrels daily for a time. The oil was struck at a depth of 2,520 feet in the Newburg sand; it is said to contain little gasoline.

The results of three distillation tests, made by the National Refining Co., of crude oil from the Cleveland district, all of which probably came from the Clinton sand, are given below.

*Distillation test of 16,000 cubic centimeters of crude oil, with a gravity of 41.2° Baumé, from Lakewood*

| Product | Per cent | Gravity (°Baumé) | Flash point (°Foster) |
|---|---|---|---|
| Gasoline fraction | 17.185 | 71.4–56.8 | |
| Kerosene fraction | 34.375 | 55.1–41.0 | 120 |
| Gas oil fraction | 12.500 | 40.6–36.7 | 260 |
| Wax oil fraction | 15.625 | 36.1–30.9 | 330 |
| Residuum | 20.315 | | |
| | 100.000 | | |

This crude oil contains a large percentage of high-grade water-white oil, which can be refined for market without the use of lead. The percentage of sulphur is very low.

*Distillation test of 11,000 cubic centimeters from a 3-gallon sample of crude oil having a gravity of 41.1° Baumé, from West Park*

| Product | Per cent | Gravity (°Baumé) | Flash point (°Foster) |
|---|---|---|---|
| Gasoline fraction | 18.18 | 80.5–57.2 | ---------- |
| Kerosene fraction | 31.815 | 53.7–40.9 | 130 |
| Gas oil fraction | 13.635 | 38.6–35.7 | 345 |
| Wax oil fraction | 13.635 | 38.6–30.4 | 365 |
| Residuum | 22.735 | ------------ | ---------- |
| | 100.000 | ------------ | ---------- |

*Distillation test of 16,000 cubic centimeters of crude oil having a gravity of 42.2° Baumé, from Cleveland*

| Product | Per cent | Gravity (°Baumé) | Flash point (°Foster) |
|---|---|---|---|
| Gasoline fraction | 20.31 | 79.4–55.8 | ---------- |
| Kerosene fraction | 31.25 | 54.6–41.2 | 122 |
| Gas oil fraction | 12.5 | 40.3–37.7 | 280 |
| Wax oil fraction | 15.625 | 35.8–31.8 | 355 |
| Residuum | 20.315 | ------------ | ---------- |
| | 100.000 | ------------ | ---------- |

## EFFECT OF STRUCTURE AND OF PHYSICAL CHARACTER OF THE SAND ON ACCUMULATION OF OIL AND GAS

In general the accumulation of shale gas in the vicinity of Cleveland is only slightly if at all affected by underground structure. Small terraces and local anticlines in the shales have long been known, and Orton [19] has mentioned one place where an arching of the shales along an axis trending N. 40° E. has possibly caused an accumulation of gas. The Mastick well, mentioned in the discussion of shale gas, was driven on the apex of this fold, but as the fold is believed to have resulted from only a surface disturbance, its influence on the accumulation of gas at depth is considered slight. In general, it is believed that these structural features have little if any relation to the occurrence of shale gas in the district as a whole.

The factors in the accumulation of oil and gas in the sands of the Cleveland gas field are discussed as follows by Rogers: [20]

In attempting to find extensions of the Cleveland field or new pools in this region a knowledge of the factors that have influenced the accumulation of the gas is very desirable. It is a common belief, especially among oil and gas operators in northern Ohio, that geologic structure has had little to do with the position of pools in the Clinton sand and that variation in the porosity of the sand itself is the controlling factor. On the other hand, it is held by many that accumulations in the Clinton are controlled by terrace structure or by minor undulations in the monoclinal slope, and it has recently been shown that the pools near

[19] Orton, Edward, Ohio Geol. Survey, vol. 6, p. 432, 1888.

[20] Rogers, G. S., The Cleveland gas field, Cuyahoga County, Ohio, with a study of rock pressure: U. S. Geol. Survey Bull. 661, pp. 27–30, map, 1918.

Wooster, 50 miles south of Cleveland, are closely associated with small anticlines.[21] If in the Cleveland region the texture of the sand is the controlling factor, a large number of dry holes must be expected in efforts to discover extensions of the field; but if structural conditions have played an important part, prospecting may be conducted more intelligently.

The Clinton sand is exceptional among important oil and gas reservoirs in that it does not crop out in the vicinity of its productive area. It rises from a great depth beneath the Appalachian coal basin, becomes somewhat thinner toward the west, and feathers out in central Ohio, where it approaches nearest the surface. The tendency of gas to migrate up the rise is generally considered the ultimate cause of its accumulation near Cleveland as well as in the great belt to the south, for it is in this general zone that its upward migration is stopped by the thinning out of the sand. The sand does not disappear completely along a single regular line; there is a border zone in which it is present only in small irregular areas, some of which, like that at Oberlin, may prove productive. As the logs of a number of wells a short distance west of the Cleveland field report the sand as absent, the field appears to be on the eastern edge of the zone in which the sand is irregular.

Although the feathering out of the sand has determined the general position of the great Clinton gas fields, structural conditions have undoubtedly operated to localize the accumulations. In many of the southern fields and as far north as Wooster the gas is not accumulated directly at the edge of the sand but has been trapped in structural irregularities a short distance below. In the writer's opinion structural conditions have also controlled the accumulation of gas near Cleveland. The field as now developed is confined entirely to a very gentle structural nose or bulge; most of the oil occurs below the gas and approximately at one structural level, and below this level the sand appears to be practically barren of either oil or gas. Aside from this local structure, the marked change in the strike of the Clinton, forming an elbow or pocket near Cleveland, has probably also furthered the accumulation of gas in this locality. [See pl. 19.]

A third condition affecting the accumulation of the gas is variation in the porosity of the sand, and this factor seems to have controlled very largely the detailed outline of the productive area and the position of the richer territory within it. In fact, the outline of the productive area is so irregular that at first sight it appears to have little relation to geologic structure. For example, the narrow and sharply defined strip of barren territory separating the West Park and Lakewood pools and extending at right angles to the strike can not be explained on structural grounds, nor can the irregular barren area on the minor structural terrace in the central part of Middleburg Township. These local variations must be attributed to the character of the sand, and it is only when the field is viewed broadly that the true significance of the structure becomes apparent.

As accumulations of gas in areas near by have probably formed under conditions similar to those in the Cleveland field, the foregoing conclusions furnish several suggestions for prospecting. It is evident, in the first place, that the Cleveland field is near the western limit of the general productive belt and that the sand becomes irregular and discontinuous to the west. Productive areas may be discovered west of the Cleveland field, but such areas are likely to be small, and prospecting for them will probably involve a number of dry holes. The zone in which the sand dies out trends somewhat west of south, however, and as prospecting continues south it may therefore be extended farther west. The eastern limit of the general productive belt can not now be determined.

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[21] Bonine, C. A., Anticlines in the Clinton sand near Wooster, Wayne County, Ohio: U. S. Geol. Survey Bull. 621, pp. 87–98, 1916.

Although in the Cleveland field the territory below the 1,000-foot contour seems to be practically barren, farther south productive areas have been found at lower levels, correspondingly farther from the thin edge of the sand. The pools near Wooster, for example, extend at least as far down the dip as the 600-foot contour (2,400 feet below sea level). Furthermore, as the strike of the Clinton turns to the east near Cleveland, the sand may be found along the lake shore to the northeast at depths of 2,000 to 2,400 feet below sea level. This area has not been seriously tested, and although such results as have been attained are chiefly negative the district should not be condemned without further exploration. Southeast of the Cleveland field the depth of the Clinton sand increases rather rapidly, and prospecting can not extend many miles in that direction.

The most favorable localities for prospecting within the area just outlined are those in which the dip of the Clinton changes in degree, and the larger accumulations of gas will probably be found in the structural irregularities so formed. The pools near Wooster are closely related to rather sharp anticlines; in the Cleveland district the structure is more gentle, but the field as a whole is confined to a broad nose. As the southern edge of this nose seems to be at Berea, the development on this particular structural feature may be regarded as already well outlined. Little is known of the detailed structure between Berea and Wooster, but it is highly probable that other noses, anticlines, or terraces exist. A sufficient number of wells have already been drilled in certain parts of this district to make possible a general comparison of the altitude of the sand at different points, and a study of this kind, supplemented if possible by an examination of the surface geology, would doubtless prove a valuable aid in prospecting. In the district east and northeast of Cleveland nothing is known of the detailed structure, and prospecting offers less chance of quick returns than in the area to the south.

Although structural conditions undoubtedly control the general position of the pools, it should be borne in mind that the character of the sand itself determines their detailed outline. One or two unsuccessful wells in an area of favorable structure do not necessarily condemn it; several of the earliest wells in the Cleveland field, put down close to what has proved highly productive territory, were dry. As a general rule the more pronounced the structure the more closely is the distribution of the gas related to it; where the structure is broad and gentle, as in the Cleveland field, the character of the sand becomes a more important factor.

## SAND AND GRAVEL

The large population of the district requires a great amount of sand and gravel for many purposes, the chief uses being for making mortar and concrete. Other uses are for gravel roofs, railroad ballast, and surfacing roads and walks. Minor uses are for molding in foundries, in sanding molds for soft mud brick, and as an abrasive for sawing stone. The sand and gravel of the district are composed of fine and coarse particles of quartz, feldspar, garnet, and magnetite, as well as pieces of granite, diorite, anorthosite, granitic gneiss, various schists, quartzite, and limestone. Some of it may have originated in each of four ways, and consequently four kinds of sand or gravel may be distinguished—glacial, lake, river, and artificial. The largest deposits in the district are of glacial origin and are found along the electric railroad connecting Akron, Bedford, and Cleveland and along the Pennsylvania Railroad near Garfield Park, where they reach a thickness of more than 60 feet. Glacial sand is generally called bank sand but consists of alternate layers of sand and gravel. Next in abundance comes lake sand, which was formed by Lake Erie at its present and higher levels, where it makes up the different lake ridges and beaches. It is also obtained from the present lake bottom, from which it is drawn up into scows by means of pumps called "sand suckers." The lake sands are apparently more rounded and worn as well as better sorted by constant wave action than the glacial or river sands. River sands are found on the flood plains and deltas of the streams. A large part of the city of Cleveland, which covers more than 25 square miles, stands on an old delta of the Cuyahoga River. The material of this delta consists of about 20 to 30 feet of sand and gravel. Artificial sand and gravel are made in two ways. The Sharon conglomerate, which consists of nearly pure white or light-yellow quartz particles very loosely cemented together, is crushed and screened and makes a fine-appearing gravel for walks and drives. It is also used with good effect as a facing for concrete bridges and buildings, and another use is in the foundation work for brick pavements. Artificial sand and gravel is also obtained by screening crushed "Euclid bluestone." In order to compare natural sand with this artificial material for use in concrete, several tests for compressive strength were made for the Euclid Concrete Co. at the Case School of Applied Science on 4-inch cubes. The figures given below are the average from six samples of each variety of sand. The tests were made when the concrete was three months old.

*Crushing strength of concrete made from various sands at Case School of Applied Science, Cleveland*

| Kind of sand | Crushing strength (pounds to the square inch of surface) | | |
|---|---|---|---|
| Proportion of sand to cement | 3:1 | 5:1 | 7:1 |
| "Euclid bluestone" screenings (run of crusher) | 2,621 | 1,813 | 940 |
| Same material as above but all below No. 60 mesh removed | 2,714 | 2,051 | 1,299 |
| Lake sand | ---------- | 1,305 | ---------- |
| Eagle Art Stone Co., glacial bank sand | ---------- | 856 | ---------- |
| Screenings of Georgia granite | ---------- | 2,046 | ---------- |
| Standard testing sand | ---------- | 870 | ---------- |

These results show that "Euclid bluestone" screenings are superior to both bank and lake sand for making mortar and concrete. This is probably due to the more angular shape and the greater range in the size of the bluestone particles.

## PEAT

Peat is partly decomposed vegetable matter and consists of remains of plants of all kinds that have either grown where the deposits are found or have been brought there. The plant accumulations are preserved from decay by being saturated with water, and hence peat usually occurs in undrained and swampy places. In the Cleveland district peat is found on the sites of many lagoons or ponds that were wholly or partly inclosed by bars and spits when Lake Erie was at the higher levels that formed the several lake ridges and beaches. When pure or when mixed with earthy matter peat forms a type of soil commonly called muck by farmers. There are about 11 places in the district where patches of muck are found, covering a total area of 768 acres.[22] In some of the local deposits the depth does not reach beyond the 3 feet that is customarily tested for soil and subsoil. That there is not very much mineral matter in some muck is shown by the fact that it burns readily when set on fire and is very difficult to extinguish. The muck areas of the district are situated as follows: 4 north and east of Berea, 1 of them somewhat large around Lake Abraham; 2 northeast of North Olmsted, 1 being rather large; 2 south of Middle Ridge, west of Dover; 1 southeast of Fields, on the Cuyahoga-Lorain county line; 1 southeast of Columbia Center, Lorain County; and 1 southeast of Northfield that is very large.

One area that is rather exceptional covers about 4 to 5 acres immediately south of Fowles Road and the Berea station of the Baltimore & Ohio Railroad (Cleveland, Lorain & Wheeling line). The peat is about 30 feet thick, according to A. H. Hudson. In the deposit are two buried pine forests with many logs and cones, one at a depth of 3 feet and the other at a depth of 6 feet. Matted grass or sedge remains were found at a depth of 10 feet. There is no recollection or tradition among the oldest settlers of living pine trees in the region. The body of peat around Lake Abraham lies between Bagley Road and the road parallel to it a mile to the north. According to Dr. D. T. Gould, of Berea, 45 feet of peat was encountered while putting in the foundations of a bridge across the stream that drains the lake. In testing for a railroad right of way on the southwest side of the lake the peat was found to have a thickness of about 70 feet. In the peat tracts south of Bagley Road and on Taylor Road depths of 10 to 12 feet were reported. Although the only present use of peat in the region is as a muck soil for growing such crops as onions, celery, potatoes, and corn, there is some possibility that the larger deposits might be utilized in the manufacture of fuel, either as air-dried blocks, as machine-pressed briquets, or as charcoal or coke, or in powder for blast-burner firing. Peat is also dried and used somewhat extensively as a fertilizer, either alone or in mixture with other fertilizing substances.

### ROAD MATERIAL

More than 90 per cent of the surface of the Cleveland district consists of clay loam and clay, which make a rather hard road when

[22] U. S. Dept. Agr. Bur. Soils, Soil map, Cleveland area, 1906

moderately dry but become dusty after prolonged drought and very sticky in wet weather. This defect has been remedied in some places by putting on sand. Gravel where accessible has been used as a top covering and makes the best dirt roads in the district. The gravel is either glacial or lake material, but in some localities, especially on drives and walks, crushed Sharon conglomerate has been used. Even where thus improved dirt roads generally do not make satisfactory travel for six months of the year, so that even in the country districts macadam, telford, and brick roads are replacing those made of dirt. Cuyahoga County first tried macadam, which was a failure, because the clayey soil carried on wheels of vehicles picked up the macadam surface. Bitulithic pavement, a mixture of tar and stone, was likewise tried but with little success, so that finally the county commissioners adopted vitrified paving brick laid on a concrete base. Paving block has proved to be very satisfactory and furthermore is procured near at hand from local shale-brick factories. In recent years new roads and some old roads as well are being paved with concrete.

## WATER RESOURCES

In the Cleveland district the annual precipitation has averaged about 35 inches over a period of 40 years. The rainfall is supplemented by the large supply of water in Lake Erie, which is accessible to most of the population of the area.

*Streams and water power.*—The streams of the district have been noted under the heading "Drainage" (pp. 18–21). The largest stream in the whole region is the Cuyahoga River, which for 20 miles runs across the Cleveland quadrangle, with a fall of about 4 feet to the mile. In the Berea quadrangle the largest stream is the Rocky River, formed by the union of the East Branch and West Branch at Olmsted. The East Branch has a fall of 16 feet to the mile and the West Branch about 11 feet to the mile. There has been very little development of water power in the district, because the fall of the larger streams is too small. In a few places on the smaller tributaries of the large streams dams have been built to supply mills with power. So far as is known the streams are not used as a source of water supply.

*Lakes.*—Aside from Lake Erie, which is the chief source of water for all uses in and around Cleveland, this glaciated region is remarkable for the absence of lakes.

*Public supplies.*—The public water supply of Cleveland is taken from Lake Erie through tunnels. The water is filtered and chlorinated. East Cleveland, Lakewood, and a number of other communities are served with water from the Cleveland supply. The water is fairly uniform in composition from year to year and from season to season. The following table gives the average of analyses of monthly composite samples made in the Cleveland waterworks laboratory during the year 1921:

*Average of analyses of water from public supply of Cleveland*

| | Parts per million |
|---|---|
| Iron (Fe) | 0.07 |
| Calcium (Ca) | 35 |
| Magnesium (Mg) | 8.4 |
| Sodium and potassium (Na+K) (calculated) | 5.6 |
| Bicarbonate radicle ($HCO_3$) | 113 |
| Sulphate radicle ($SO_4$) | 25 |
| Chloride radicle (Cl) | 11 |
| Total dissolved solids | 159 |
| Total hardness as $CaCO_3$ (calculated) | 122 |

Berea, which is the largest town in the district outside of Cleveland and its suburbs, pumps its water supply from some of the large quarries in the Berea sandstone that have been abandoned by the Cleveland Stone Co.

*Underground water.*—Although most of the population of the district is supplied by Lake Erie, the inhabitants of the larger part of the territory, probably 400 square miles, are dependent on underground water. There are many alternations of sand and gravel with clay in the glacial drift that are capable of storing large amounts of water. The contact of the glacial drift with the underlying Bedford, Orangeville, and Meadville shales is also a source of water, especially where the drift is thick and consists largely of sand and gravel. Other formations are the Sharon conglomerate, the Berea sandstone, and the Euclid sandstone lentil, near the base of the Bedford shale. Even in the Cleveland, Chagrin, and underlying shales of Portage age there are many water-bearing sandstone strata. In the upper part of the Chagrin shale there are several sandy beds that are porous enough to contain water. The rocks in this area to a depth of more than 1,000 feet, however, are prevailingly shales, which contain little water. There is one deep-seated water-bearing stratum in the Silurian limestone known as the Big lime, just below the Newburg gas sand. It is called the Big Water, is reached at depths of about 2,400 to 2,600 feet, and has caused more or less trouble in drilling for gas. Another water-bearing layer is reached at a depth of about 1,400 feet.

Most of the wells of the district are dug, but a few have been drilled. Most of the dug wells do not exceed 30 feet in depth. In places where the Berea sandstone approaches the surface the wells are sunk to this formation. A drilled well near Columbia Station, Lorain County, 78 feet deep, goes through 35 feet of drift and extends 43 feet into the Berea sandstone. At first it showed some oil, and it still contains perceptible amounts of hydrogen sulphide that has probably originated from gas and oil in the Berea itself or in the thick underlying shales. The water table in the area is generally near the surface.

*Springs.*—There are many springs in the area, most of which are near the contact of the glacial gravel and sand with the Bedford, Cleveland, or Chagrin shales. Water is bottled and sold from Alba, Minnehaha, Rockport, Peerless, and Puritas Springs at Rockport and from Purity Spring near Luna Park, Cleveland. As the Berea sandstone, Euclid sandstone, and Cleveland and older Devonian shales contain considerable pyrite, many spring waters that issue from them contain appreciable amounts of iron sulphate, which gives a slightly astringent taste. As the iron is oxidized to limonite when such water reaches the surface, the springs have been called "iron" springs. Several springs of this type are situated on the Shaker Heights Boulevard, Cleveland. Several springs within the district contain hydrogen sulphide. One of these issues from a crack in the Berea sandstone on the south side of the viaduct over Tinkers Creek at Bedford.

## SOILS

*General character.*—The value of a soil for agriculture depends somewhat upon the climate but more upon its physical and chemical properties. The most valuable chemical constituents are silica, alumina, iron oxide, lime, magnesia, soda, potash, phosphoric acid, and nitric acid. If any of the more necessary of these are scanty, the deficiency may be remedied by the addition of fertilizers. The physical properties of soil include texture, structure, and of lesser note color and weight. By texture is meant the size of the constituent particles, which are classed from coarse to fine as gravel, sand, silt, and clay.

The soils of the Euclid, Cleveland, and Berea quadrangles are the source of considerable wealth, although the underlying rocks of the region are prevailingly shales with some sandstone in the western part, and these rocks on weathering do not produce very fertile or desirable soils. By far the largest part of the soil of the area is transported glacial material derived from the late Wisconsin drift sheet. In places where the drift is not thick, the soil is composed in part of glacial material and in part of disintegrated shale, sandstone, or conglomerate. Most of the soils of glacial origin have been derived from till and have been modified into silty or clayey loams, which are cold, heavy, wet soils and cause late crops. The materials of this till were transported chiefly from Canada, but as the strike of the local shale and sandstone is nearly east or northeast they crop out in belts that run in these directions. Consequently some fragments from the more northerly strata find their way along with the drift into the belts lying on the south and produce an effect upon the soil. In some few places where the soil is derived from more or less stratified drift, the level surfaces are covered with a clayey or loamy soil, and the slopes are more gravelly. Another type of transported soil is partly of lacustrine and partly of alluvial origin. Such soils consist of loam, sandy loam, and gravelly loam and are found chiefly on the terraces, flood plains, and deltas of the streams and on the higher beaches of old Lake Erie. The nearest approach to an indigenous residual soil in the district is the so-called DeKalb clay. In the areas occupied by this soil the drift is very thin or entirely absent. Another indigenous soil in the region is mainly of organic origin and may be called a humous soil. It is found in undrained, swampy regions, where the growth of vegetation has been rapid and decay slow. It is black and of loose texture and is described under "Peat."

*Classification.*—The soils of the district have been mapped, classified, and described by the Bureau of Soils.[23] The soils in all but 21,888 out of 326,016 acres consist of loams, which are far more desirable than clays. However, all the loams except the Dunkirk fine sandy loam contain 20 per cent or more of clay, which is sufficient to produce a rather heavy cold soil. The Miami clay loam covers 74.7 per cent of the total area and is a transported glacial soil derived from till and modified by some residual soil. The Dunkirk clay is a transported glacial soil consisting of fine material deposited in basins with poor drainage. The Miami stony loam is a glacial soil derived from till and modified by Berea grit and Sharon conglomerate, and the Dunkirk loam is largely the same material modified by Berea grit. The Dunkirk fine sandy loam and the Dunkirk gravelly loam are transported lacustrine and alluvial soils found on the old lake beaches and on the terraces, flood plains, and deltas of the larger streams, including the Cuyahoga River and the East and West Branches of the Rocky River. The gravelly loam consists of coarser particles that have been sorted by wave action on the beaches, but some has been formed on the slopes and terraces of the valleys from coarse material from which finer particles have been washed to lower levels. The Dunkirk fine sandy loam occurs especially along North and Middle Ridges and on the old Cuyahoga delta, upon which Cleveland is chiefly built. The Wabash loam is a transported alluvial soil formed as flood-plain deposits along the valleys of the streams. The DeKalb clay is a residual soil formed from the disintegration of Chagrin shale. It follows the strike of the shale and occurs in a narrow belt from a quarter of a mile to a mile wide, which runs parallel to the shore of Lake Erie from Dover Bay through Lakewood and Nottingham to Wickcliffe. An analysis of it is given on page 105 (analysis 1) and several of the Chagrin shale, which lies

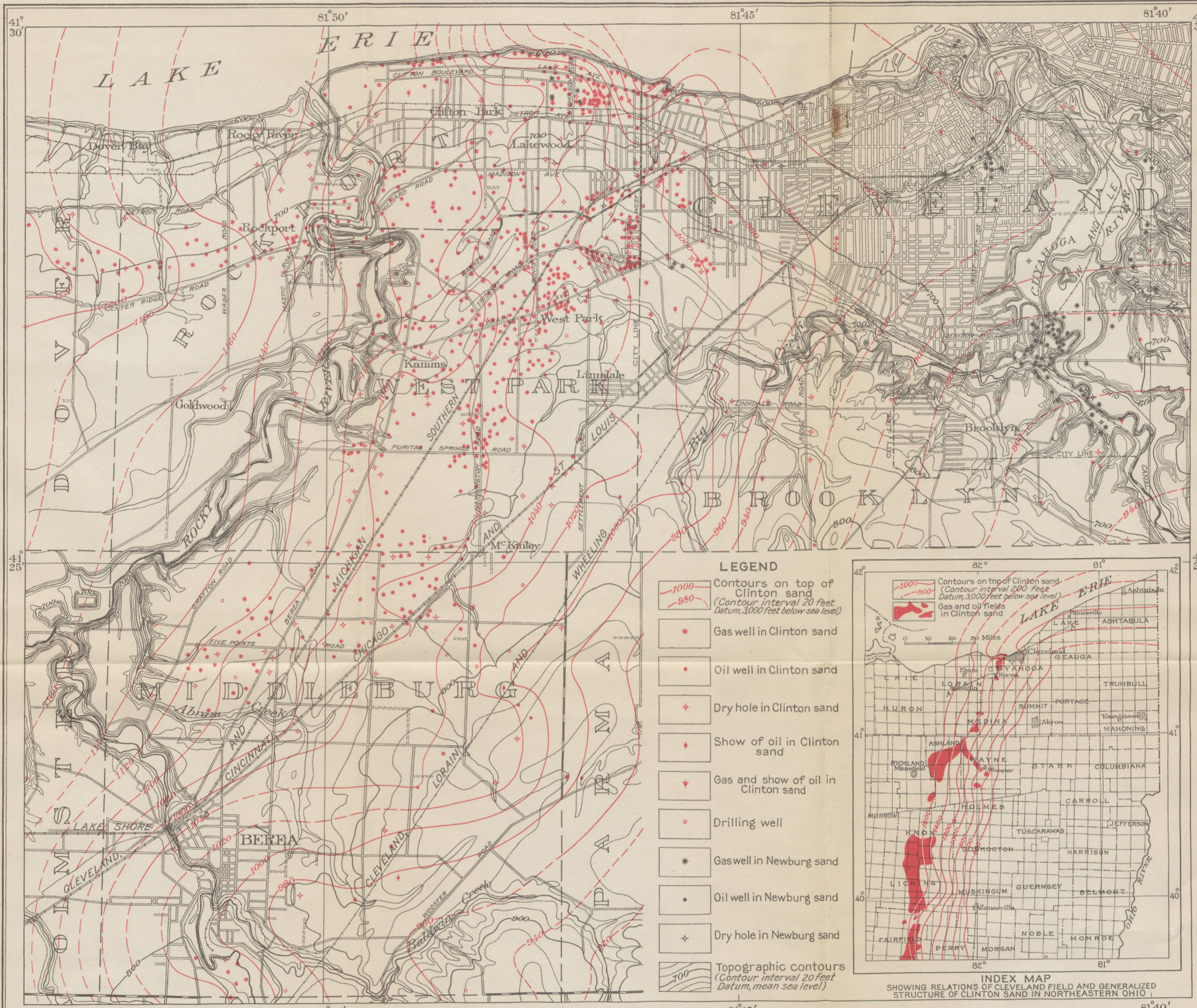
[23] Lapham, J. E., and Mooney, C. N., Soil survey of the Cleveland area, Ohio, U. S. Dept. Agr. Bur. Soils, 1906.

beneath it, on page 106. A comparison of these analyses shows a decided similarity, but the DeKalb clay has lost part of the more soluble constituents, including alkalies, lime, magnesia, and iron, as would be expected. "Meadow" is a term applied to marsh soils that are found in swampy areas occupied by marsh vegetation. For convenience a summary is given below, showing the classification and areas of soils of the district and their origin.

*Soils of the Cleveland district*

| Name of soil | Area | | Geologic classification | Origin |
|---|---|---|---|---|
| | Acres | Percent | | |
| Miami clay loam | 243,456 | 74.7 | Transported, glacial | Till modified by some residual soil. |
| Dunkirk fine sandy loam | 27,328 | 8.4 | Transported, lacustrine and alluvial. | Finer sediments deposited on lake beaches, flood plains, and deltas. |
| Wabash loam | 14,080 | 4.3 | Transported, alluvial | Flood-plain deposits. |
| Dunkirk clay | 10,688 | 3.3 | Transported, glacial | Finer glacial material deposited in basins with poor drainage. |
| DeKalb clay | 9,728 | 3.0 | Indigenous, residual | Largely weathered Chagrin shale. |
| Dunkirk gravelly loam | 8,384 | 2.6 | Transported, lacustrine and alluvial. | Coarser sediments deposited as lake beaches, flood plains, and deltas. |
| Miami stony loam | 8,000 | 2.5 | Transported, glacial | Till modified by Berea sandstone and Sharon conglomerate. |
| Dunkirk loam | 2,880 | .8 | do | Till modified in part by Berea sandstone. |
| Muck | 768 | .2 | Indigenous, organic | Peaty substance mixed with earthy matter. Caused by poor drainage. |
| Meadow | 704 | .2 | Marsh soil | Swampy deposits with marsh vegetation. |
| | 326,016 | 100.0 | | |

# INDEX




Base from Berea and Cleveland U. S. G. S. topographic maps

Structural geology by G. Sherburne Rogers

# MAP OF CLEVELAND GAS FIELD, CUYAHOGA COUNTY, OHIO

SHOWING GEOLOGIC STRUCTURE

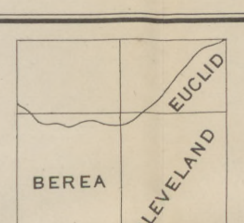
Scale $\frac{1}{62,500}$

1 ½ 0 1 2 3 Miles

1917


Base from U. S. G. S. maps of Euclid, Cleveland, and Berea quadrangles. Surveyed in 1901–2

WILLIAMS & HEINTZ CO. WASH. D.C.




INDEX OF QUADRANGLES

TRUE NORTH
MAGNETIC NORTH
APPROXIMATE MEAN DECLINATION 1929

# MAP OF THE EUCLID, CLEVELAND, AND BEREA QUADRANGLES, OHIO, SHOWING AREAL GEOLOGY

Scale $\frac{1}{62500}$

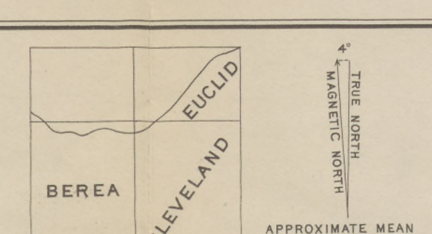
Contour interval 20 feet east of 81° 45', 10 feet west of 81° 45'.
*Datum is mean sea level.*

1931

Geology east of 81° 45' by H. P. Cushing, 1905–1907
Geology west of 81° 45' by H. P. Cushing and C. R. Stauffer in 1907–1908.


Base from U. S. G. S. maps of Euclid, Cleveland, and Berea quadrangles. Surveyed in 1901–2

WILLIAMS & HEINTZ CO.,WASH.,D.C.

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APPROXIMATE MEAN DECLINATION 1929

# MAP OF THE EUCLID, CLEVELAND, AND BEREA QUADRANGLES, OHIO
## SHOWING PLEISTOCENE GEOLOGY

Scale $\frac{1}{62500}$

Contour interval 20 feet east of 81° 45′, 10 feet west of 81° 45′
*Datum is mean sea level*

1931

Pleistocene geology by Frank Leverett, 1920