GEOLOGICAL SURVEY OF OHIO

J. A. BOWNOCKER, State Geologist

FOURTH SERIES, BULLETIN 30

GEOLOGY OF DELAWARE COUNTY

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COLUMBUS
1926

Published by authority of the Legislature of Ohio, under the supervision of the State Geologist.

Printed by the Kelly-Springfield Printing Company
Springfield, Ohio

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CHAPTER I

INTRODUCTION

Location, Topography, and Drainage

Delaware County lies almost exactly at the center of the State of Ohio (Fig. 1), and includes parts of the Delaware, Marengo, Dublin, and Westerville sheets of the topographic map of the United States.[1]

The county is a part of the nearly level surface of the upper Scioto drainage basin. If we leave out of account, for the moment, the stream valleys, the central and western part of the county is an almost level plain standing about 950 feet above sea level and sloping slightly to the south. Eastward this plain rises to about 1,200 feet along the Scioto-Licking divide, which takes a winding north-south course just beyond the east border of the county. On the west, beyond the county line, the plain rises more gently to the Scioto-Miami divide, which follows a north-south course about on the boundary between Logan and Union counties. Delaware County is thus seen to lie on the east side of a wide and very shallow basin, inclined gently to the south—the valley of the Scioto and its tributaries.

The most striking scenic feature of the county is its flatness. Large areas back from the streams appear to the eye perfectly horizontal. From this nearly level surface departures are to be noted in two directions. Rising above it, belts of gently rolling country (glacial moraines) reach heights of between 40 and 50 feet, but as these belts are from one to three miles in width they do not make conspicuous features in the landscape. In addition to the moraine belts, small hills of sand and gravel (glacial kames and eskers) are found in several parts of the county, rising rather sharply from the plain. A line of such hills extends southeast from Prospect to beyond Radnor, and other isolated gravel hills are found in the eastern part of the county.

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[1]The United States Geological Survey has prepared, in co-operation with the State of Ohio, a topographic map of the State on a scale of 1 to 62,500, or almost exactly one mile to the inch. This map is published in about 200 sheets or quadrangles, each sheet a quarter of a degree on a side, and named from some city or village within its limits. The maps show streams, roads, political divisions, and, by means of contour lines, elevations above sea level and surface configuration. They are exceedingly useful and should be much more widely known and used than they are. They cost 10 cents each, or, in lots of fifty or more, 6 cents each, and can be obtained by addressing The Director, U. S. Geological Survey, Washington, D. C. Payment should be in cash or money order, not in stamps. The whole of Ohio has been mapped and an index map showing the location of all the sheets can be gotten from the same address free.

The second departure from the generally level surface of the county is the valleys cut below it. Four streams, the Scioto, Olentangy, Alum Creek, and Big Walnut Creek, cross the county in nearly parallel north-south courses. The last three are tributaries of the Scioto and enter the latter at or below Columbus. All have cut valleys, increasing in depth

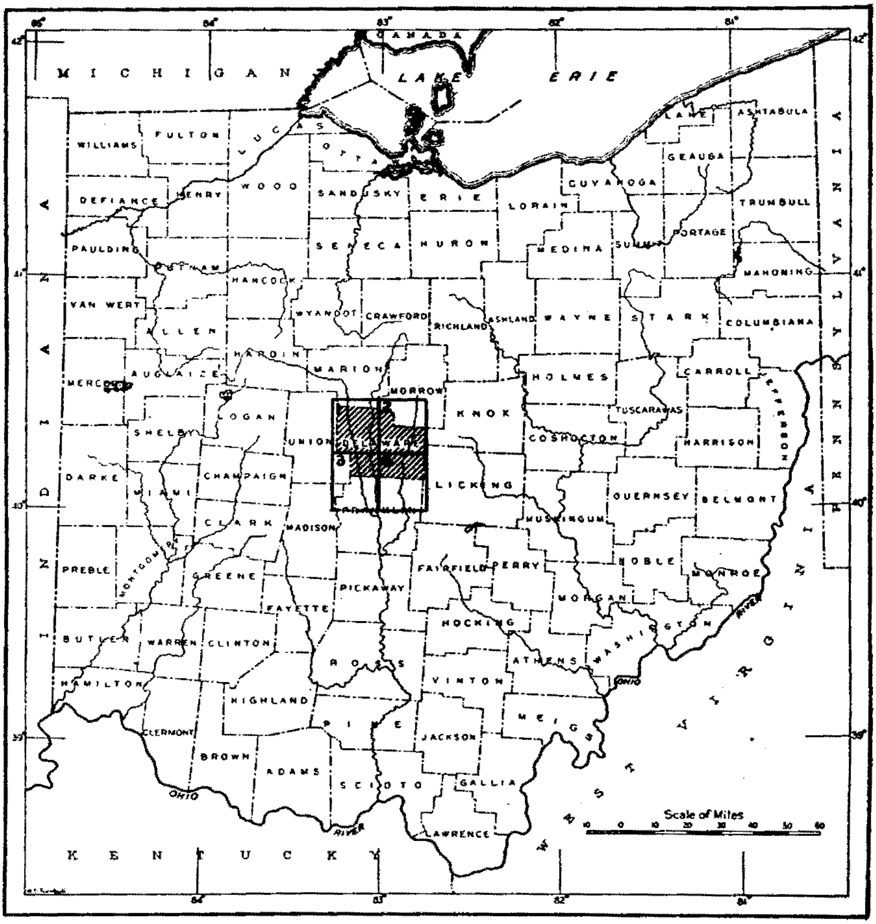


Fig. 1. Index map.

The four rectangles are the topographic sheets; 1. Delaware, 2. Marengo, 3. Dublin, 4. Westerville.

to the south. The following table gives the height of the stream beds above sea level at the north and south boundaries of the county and the depths to which the valleys are cut below the average level of the surrounding plain. The measurements are taken from the topographic map and are approximate only.

	Scioto	Olentangy	Alum Creek	Big Walnut
Stream elevation at north border of the county	889	900	910	1078
Depth below adjacent upland	20	40	50	40
Stream elevation at south border of the county	772	754	803	833
Depth below adjacent upland	138	120	85	67

In the northern part of the county the streams are flowing in shallow valleys, generally on glacial drift and with few exposures of bed-rock. In the central and southern parts, as a result of the increased depth of the valleys and the common presence of rocky cliffs in the valley sides, the scenery along the streams is much more attractive and in striking contrast to the generally flat surface of the upland.

As already noted, the main drainage of the county consists of four south-flowing streams. These are so closely spaced that no tributaries of any size enter them from the inter-stream areas. Longer branches do enter the Big Walnut from the east and tributaries of even greater length, heading in the high country east of Bellefontaine (Fulton, Bokes, Mill, and Darby creeks), enter the Scioto from the west.

Physiographic Divisions

Figure 2[1] shows the physiographic divisions of Ohio and adjacent regions. The line separating the Appalachian Plateau and the Interior Plains parallels the shore of Lake Erie to west of Cleveland, and then continues west of south across the central part of the State, passing into Kentucky a little west of the Scioto River. Southeast of this line, in the Allegheny Plateau, the rocks are shales and sandstones, and the country is rougher and higher. The slightly larger northwestern half of the State lies in the Central Lowland section of the Interior Plains. The rocks are more easily eroded shales and limestones, and the surface is lower and more even. Two divisions of the Central Lowland of Ohio are made by a roughly east-west line about fifty miles south of the Ohio-Michigan boundary. The area to the south is the Till Plains division, that to the north is the Eastern Lake section. The northern area includes that part of Ohio covered by the waters of the great temporary lakes which formed in the Erie Basin during the closing stages of the last ice age. It is the northward extension of the Till Plains, veneered by lake deposits.

Delaware County lies in the Till Plains section of the Central Lowland, its eastern line about ten miles west of the western edge of the Allegheny Plateau.

It is worth noting that though the divide between two of the great

[1]Figure 2 follows Fenneman, Physiographic divisions of the United States, Annals Assn. American Geographers, Vol. VI, pp. 19–98, and map, Pl. I.

drainage basins of North America, namely the Mississippi and the St. Lawrence, crosses northwestern Ohio in an east-west direction, it is quite impossible to recognize it as a topographic feature. As one crosses it on the railroad he seems to be passing through a continuous and nearly level plain.

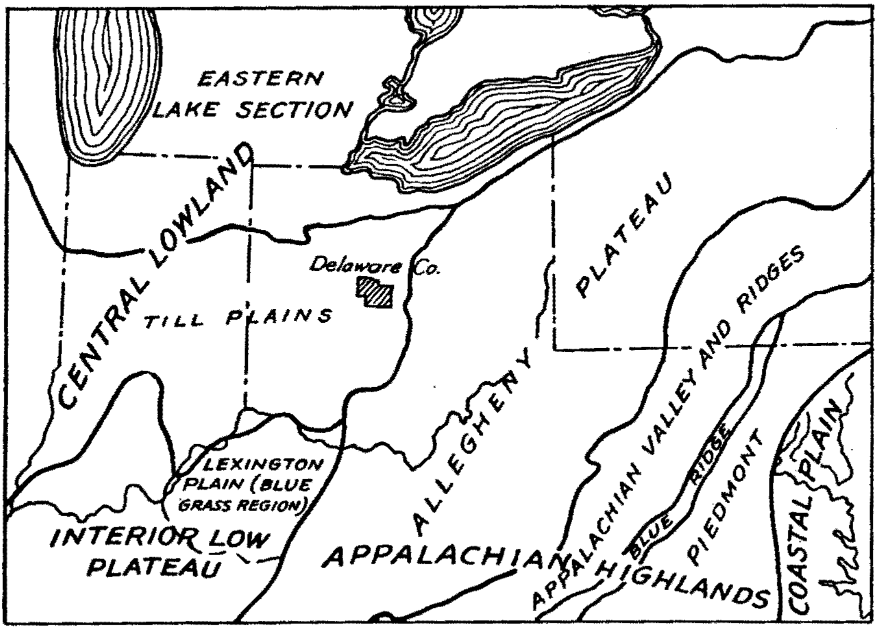


Fig. 2. Physiographic divisions of Ohio and adjacent territory.

General Geological Features; Preliminary Statement

The geological features of Delaware County are simple and will be considered in detail in the succeeding chapters. The whole of the county, except the valley bottoms which are floored with river deposits, is covered with a compact, yellow boulder-clay or till, of varying thickness up to fifty feet, which is the direct deposit of the ice of a continental glacier. In a few places, especially in a belt extending southeast from Prospect to beyond Radnor, masses of sand and gravel are found, made by waters at the ice front during the northward retreat of the glacier.

Beneath this surface covering of incoherent boulder-clay and river sand and gravel lies the bed-rock. This consists of a series of limestones, shales, and, in less amount, sandstones, which lie one above another like layers of cardboard, and slope down or dip to the east at an average rate of about 25 feet to the mile. Since the surface of the county is nearly horizontal or even rises slightly to the east, it cuts across the inclined rock formations which consequently occur at the surface in north-south belts, the oldest formations on the west side of the county, the younger occurring successively to the east. The Olentangy River makes approximately the boundary between the older limestones of the west half of the county (and of the State), and the shales and sandstones of the east half of the county (and of the State as well). In Delaware County the easterly dip of the beds carries the limestones beneath the surface east of the Olentangy.

Bibliography

There is listed below, in order of date of issue, the chief publications which deal with the geology of Delaware County. Other more special publications will be referred to in the body of the bulletin.

Winchell, N. H. Report on the geology of Delaware County. Report Geol. Survey of Ohio, Vol. II, pt. 1, pp. 272–313. 1874.

This is the only previous geological report on the county and was issued fifty years ago.

Leverett, Frank. Glacial formations of the Erie and Ohio basins. U. S. Geol. Survey, Monograph 41. 1902.

Leverett's volume is a general description of the glacial features of the State, and his map (Plate II) is even in detail good for Delaware County.

Prosser, C. S. The Sunbury shale of Ohio. Jour. of Geology, Vol. X, pp. 262–312. 1902.

Prosser, C. S. The Delaware limestone. Jour. of Geology, Vol. XIII, pp. 413–442. 1905.

Swartz, C. K. The relation of the Columbus and Sandusky formations of Ohio Johns Hopkins Univ. Circular, New Series No. 7, pp. 56–65. 1907.

Lapham, J. E., and Mooney, C. N. Soil survey of the Westerville area, Ohio, U. S. Dept. Agriculture, Bureau of Soils, Field operations of the Bureau of Soils, 1905, pp. 715–729. 1907.

This report covers the Dublin and Westerville quadrangles, and the description and conclusions can be extended easily over the rest of the county.

Stauffer, C. R. The Middle Devonian of Ohio. Geol. Survey of Ohio, Fourth Series, Bull. 10. 1909.

Bulletin 10 is a detailed account of the Middle Devonian limestones through the State, and includes detailed sections and fossil lists from various places in Delaware County. It must be taken as the foundation for any study of the limestones.

Stauffer, C. R., Hubbard, G. D., and Bownocker, J. A. Geology of the Columbus Quadrangle. Geol Survey of Ohio, Fourth Series, Bull. 14. 1911.

The Columbus bulletin is a geological description of the east and west Columbus and the Dublin and Westerville quadrangles. The Columbus quadrangle, scale two miles to the inch, covers the same area as the four inch to the mile sheets, the east and west Columbus, the Dublin and the Westerville, and the northern part of the last two includes about two-fifths of Delaware County. In preparing the present bulletin constant use has been made of the Columbus bulletin, though that part of Delaware County covered by it has been gone over independently in the field, both as to the bed-

rock and the surface geology, and in places the maps accompanying this volume differ from those in the Columbus bulletin.

Hubbard, G. D., Stauffer, C. R., Bownocker, J. A., Prosser, C. S., and Cumings, E. R., Columbus Folio, U. S. Geol. Survey, Folio 197, 1915.

This is the republication, in slightly different form, of Bulletin 14 of the Geological Survey of Ohio.

Bownocker, J. A. Geological Map of Ohio. 1920.

In addition to the reports listed above, the geological map of the State must be included in any bibliography of any of the counties.

Acknowledgments

The writer has had at various times the assistance of students in the geological department of Ohio Wesleyan University. The following have done field work which has been used in the preparation of this bulletin either in the text or in the geological map of the bed-rock formations: John N. Hollister, '11; Arthur C. Bevan, '12; Arthur S. Littick, '16; Merton R. Steele, ex. '25; Andrew Ireland, '25; M. Combie Smith, '26. Miss Phyllis Draper, '27, has identified the algae of the iron and sulphur springs.

CHAPTER II

BED-ROCK GEOLOGY

Introductory

The word rock, as commonly used, means, among other things, something hard. Geologists, however, use the word in a wider sense to include not only the hard limestone or sandstone of the quarry or ledge but the more or less loose and incoherent deposits of sand or gravel which commonly lie above and conceal the hard rock below. The geologist is therefore obliged to distinguish:

1. The mantle-rock, more or less soft, loose, and incoherent, which occurs at the surface and more or less completely conceals or mantles the underlying hard rock.

2. The bed-rock, usually hard and coherent, which is everywhere found beneath the mantle-rock and is seen either in natural exposures like cliffs along valley sides and the rock bottoms of streams or in artificial openings like quarries.

In Delaware County the bed-rock is all but universally hidden beneath the mantle-rock and shows only where streams have cut through this mantle of glacial drift. It is easily distinguished from the mantle-rock, is vastly older, and of a wholly different origin.

The bed-rock comprises limestones, shales, and some sandstones, grouped in a series of formations. A formation, as defined by the U. S. Geological Survey, "contains between its upper and lower limits either rocks of uniform character or rocks more or less uniformly varied in character, as, for example, an alternation of shale and limestone." It is implied that rocks will not be placed in separate formations unless they differ in physical character. The three limestones differ from one another in color, grain, and bedding, and usually can be recognized even in hand specimens. The shales are also easily separated. The Cuyahoga formation is more variable than any of the others and consists of alternating layers of thin sandstone and sandy shales, so that it is not strictly correct to call it either sandstone or shale: it is simply the Cuyahoga formation. Each of these formations extends far beyond the borders of the county and is named from some place where it is well shown. All of these places, except Monroe (Michigan), are in Ohio and the type localities for three of them—the Delaware limestone and Olentangy and Sunbury shales—are within the limits of the county.

Human history is commonly divided into ancient, medieval, and modern time. In quite analogous fashion geological history has its ancient, medieval, and modern time, known respectively as the Paleozoic, Mesozoic, and Cenozoic eras. These geological divisions are

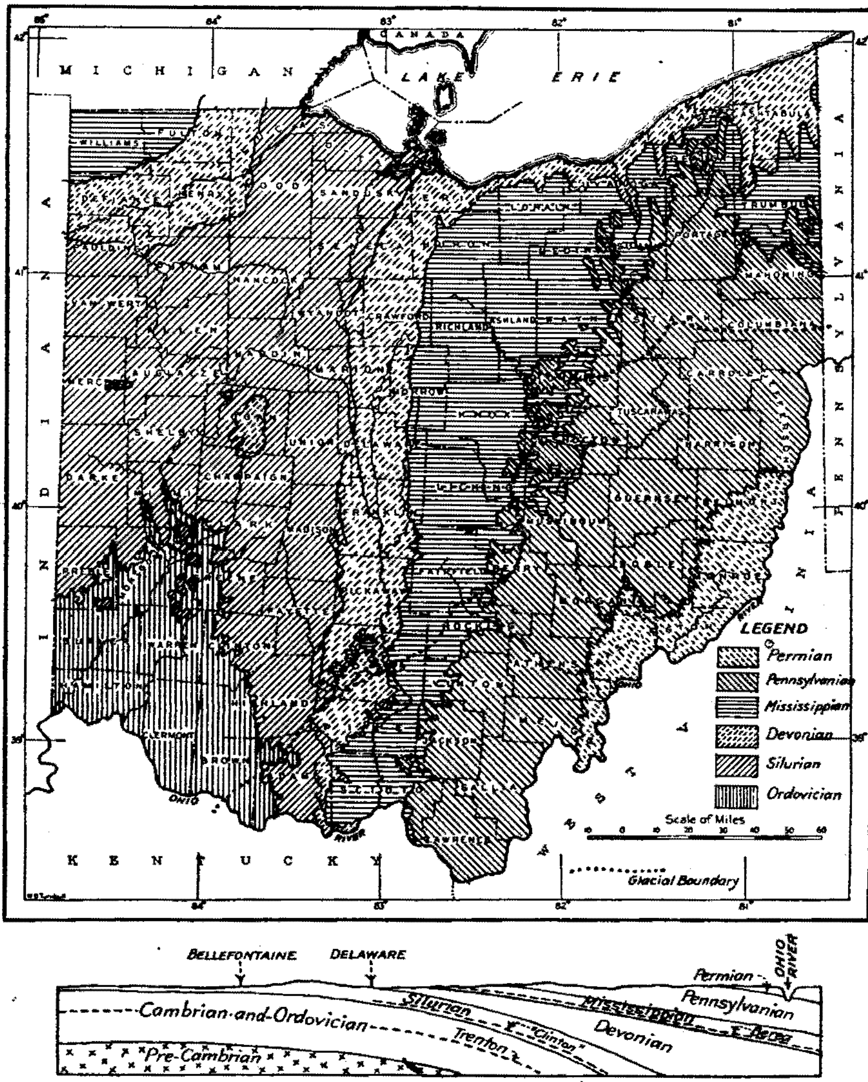
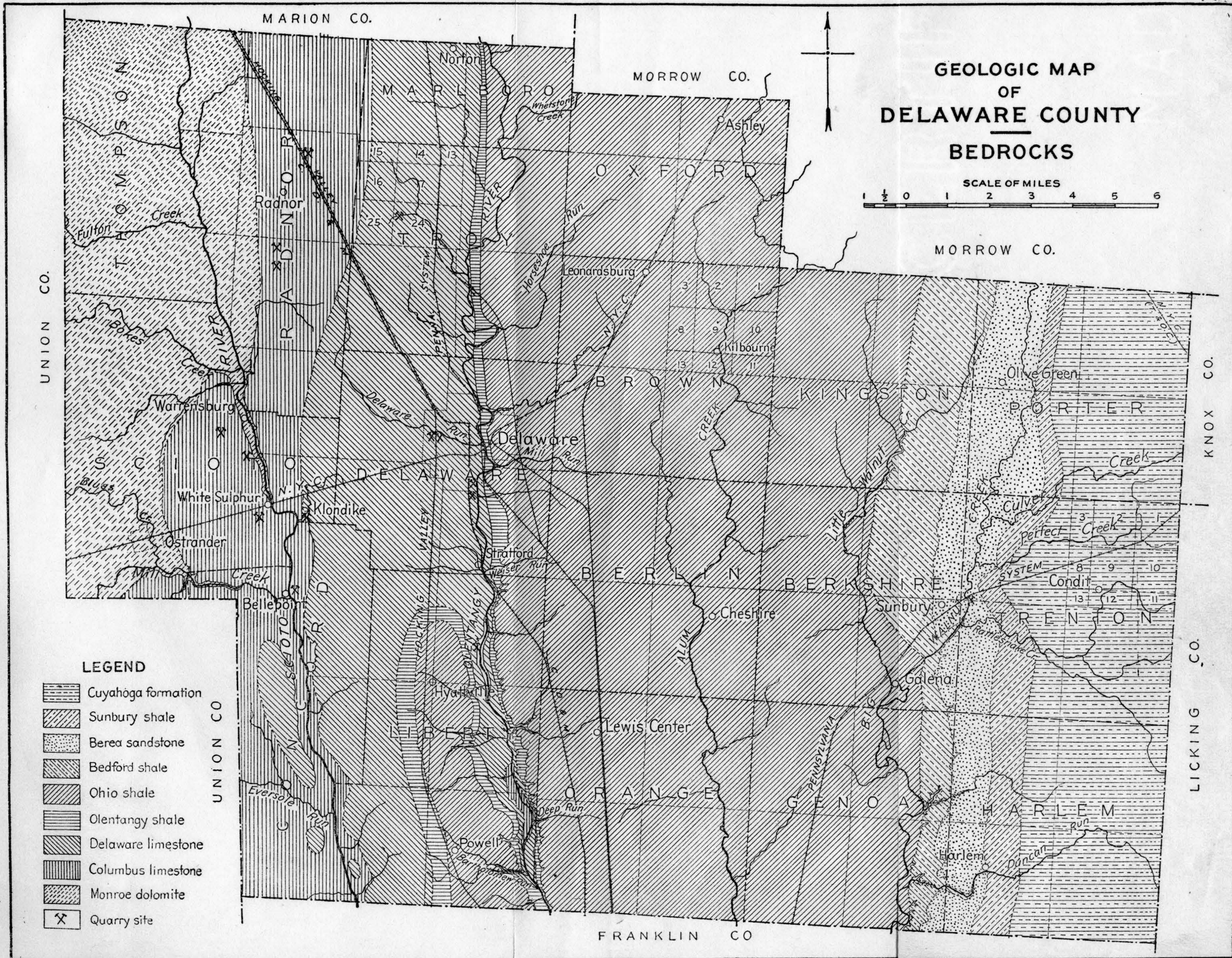


Fig. 3. Geologic map of Ohio.

Below is a cross section from Bellefontaine, Logan County, through Delaware to the Ohio River.

of course immensely longer than the divisions of human history; where the latter are measured in centuries, the former are measured in millions of years. The rock formations of Delaware County were formed in


GEOLOGIC MAP
OF
DELAWARE COUNTY
BEDROCKS
SCALE OF MILES
1 ½ 0 1 2 3 4 5 6
MARION CO.
MORROW CO.
MORROW CO.
UNION CO.
UNION CO
KNOX CO.
LICKING CO.
FRANKLIN CO
THOMPSON
RADNOR
MARLBORO
TROY
OXFORD
BROWN
KINGSTON
PORTER
SCIOTO
DELAWARE
BERLIN
BERKSHIRE
TRENTON
CONCORD
LIBERTY
ORANGE
GENOA
HARLEM
Norton
Ashley
Radnor
Leonardsburg
Kilbourne
Olive Green
Warrensburg
Delaware
White Sulphur
Klondike
Ostrander
Stratford
Bellepoint
Cheshire
Sunbury
Condit
Galena
Hyattsville
Lewis Center
Powell
Harlem
LEGEND
Cuyahoga formation
Sunbury shale
Berea sandstone
Bedford shale
Ohio shale
Olentangy shale
Delaware limestone
Columbus limestone
Monroe dolomite
Quarry site

mid-Paleozoic time—in the late Silurian, Devonian, and early Mississippian—how long back in years no one can tell; 100,000,000 years? Perhaps; that is about what Pirsson and Schuchert make it in the last edition of their Text-book of Geology. No bed-rocks of Delaware County or of Ohio are younger than the Paleozoic and for the many million years of the Mesozoic and of the Cenozoic, up to the comparatively recent glacial period, there is no record of rock formation, either in the county or in the State. It is a blank that has to be filled in from information gathered outside the State.

Each of the formations mentioned is a great sheet of rock. The Columbus limestone, for example, is 80 feet thick, but it has very great horizontal extent. It stretches north and south beyond the borders of the State and is found in a northeast-southwest belt running from the Hudson Valley near Albany for 500 miles as far as Virginia. Its width is 250 miles. If we take its thickness as 80 feet and its width as 250 miles, the ratio of thickness to width is about 1:16,000. The ratio of thickness to width of a sheet of typewriter paper of medium thickness is about 1:4000, so that it is not misleading to refer to the formations as sheets. Some formations are thinner than the Columbus limestone which has been taken as an example, some are much thicker, but even these last may be accurately compared to thin sheets of cardboard.

The rock sheets or formations of the Delaware region are not quite horizontal, they slope down or dip to the east at an average rate of about 25 feet per mile. The general rock surface underneath the mantle-rock, however, is nearly level. In consequence, the rock formations are cut across at the surface and occupy roughly north-south belts, the lowest and oldest rocks being found on the west side of the county while the younger and higher are found successively east. These relations are brought out on the map (Fig. 3), drawn to show the distribution of the formations on the surface, and in the profile section (Fig. 3), which gives their underground positions. It can be seen that each system except the Permian extends east beneath all higher and younger systems and east of its surface outcrop can be reached only by drilling.

The bed-rocks of Delaware County are without exception marine sediments, as is shown by the presence in them of fossils of marine animals. They belong to a time when the geography of northeastern United States was radically unlike that of today, to a time when Central Ohio was beneath the waters of a wide shallow sea, the nearest land many miles distant to the southeast and north, or perhaps somewhat nearer to the west. In that shallow sea limy muds, augmented with the shells of marine organisms, accumulated during Middle Devonian time. Then later, in muddy seas, were laid down the clays and sands of Olentangy to Cuyahoga time. The deposits, compacted, hardened, and later elevated above sea level and exposed to the eye by erosion, are our rocks of today, our limestones, shales, and sandstones.

Age of Rocks

The formational and time equivalence of the bed-rocks of Delaware County are shown in the table below:

Era	System		Epoch	Delaware County Formations
Paleozoic	Mississippian		Waverlyan	Cuyahoga formation
				Sunbury shale
				Berea sandstone
				Unconformity
				Bedford shale
	Devonian	Upper	Chautauquan and Senecan	Ohio shale
				Olentangy shale
				Unconformity
		Middle	Erian	Delaware limestone
			Ulsterian	Columbus limestone
		Lower		Absent
	Unconformity			
	Silurian	Upper	Cayugan	Monroe dolomite

As will be noted later in the discussion of the separate formations, there are differences of opinion as to the position of some of the unconformities in the county; in the table, however, it is not possible to show alternative views, and it is necessary to show arbitrarily the one which seems most probable.

The Geological Column

Figure 4 is a columnar section of the bed-rocks exposed at the surface in Delaware County. The underlying formations can be known directly only from well logs. The logs of wells drilled in Delaware County have been lost. Figure 5 is the log of a well drilled in Columbus to the Trenton limestone. As it is not likely that any considerable change takes place either in the thickness or the character of the formations in the 24 miles between Columbus and Delaware, this section may be taken as substantially correct for Delaware County. In Figure 5 the top of the Trenton is 1,855 feet below the base of the Delaware limestone. If 45 feet are added for the thickness of the Delaware, the top of the Trenton is 1,900 feet below the top of the Delaware, which is the top of the limestone series of central Ohio. At Delaware that would be 1,900 feet below the level of the Olentangy River, which is flowing on the top of the limestones.

The sedimentary rocks of Ohio lie on a base of ancient pre-Cambrian crystalline rocks. These rocks do not come to the surface any-

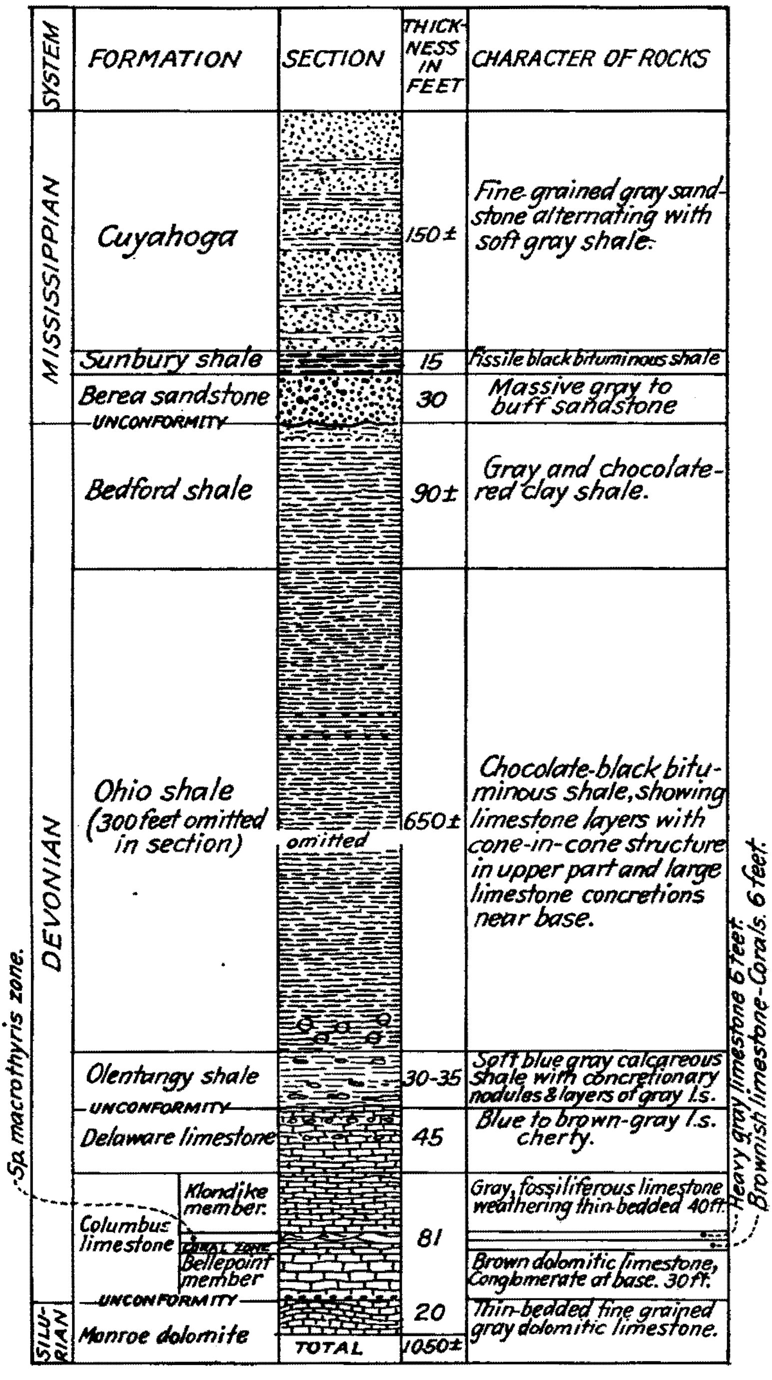


Fig. 4. Columnar section of surface rocks of Delaware County.

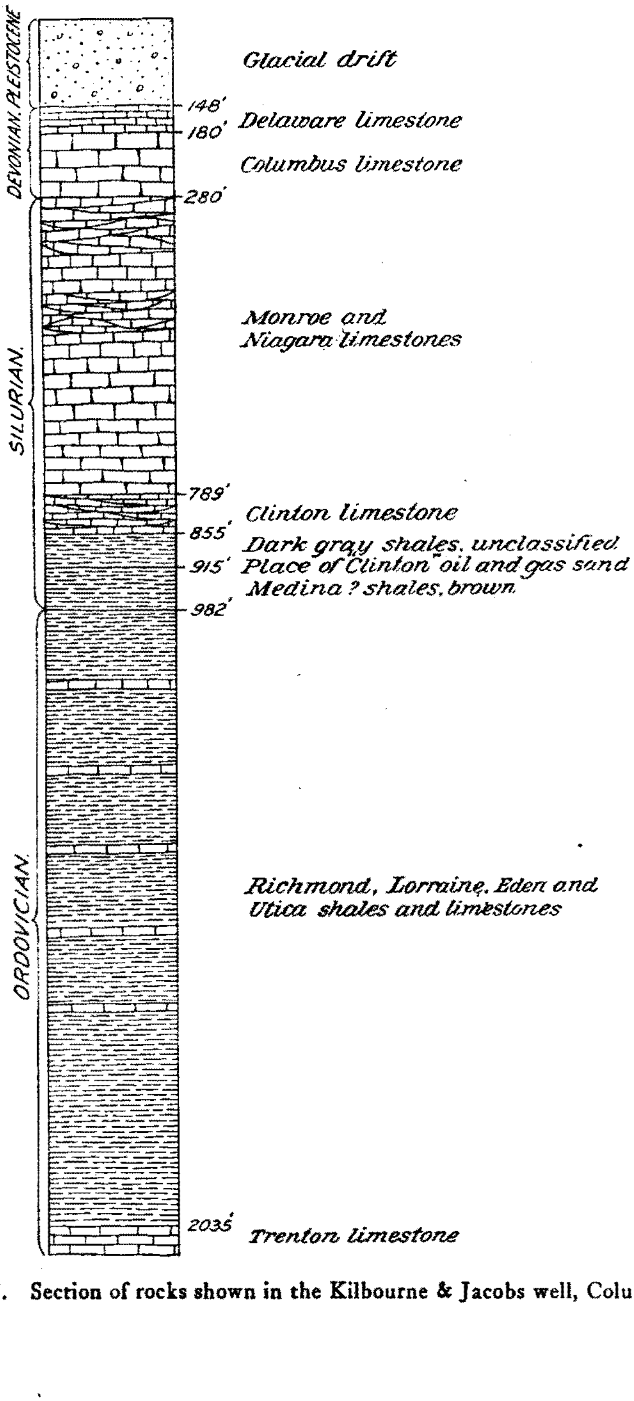


Fig. 5. Section of rocks shown in the Kilbourne & Jacobs well, Columbus.

where within the limits of the State, but have been reached in two deep wells.[1] One of these is at Waverly, 67 miles south of Delaware, the other is at Findlay, 59 miles northwest (N. 30° W.) of Delaware. The following table gives the depths at which the Trenton limestone, St. Peters sandstone, and pre-Cambrian rocks are found in the wells, and the Trenton-St. Peters and Trenton-pre-Cambrian intervals:

	Waverly	Findlay
Top of Trenton limestone	2,100	1,165
Top of St. Peters sandstone	2,825	1,894
Pre-Cambrian base	3,320	2,770
Trenton-St. Peters interval	725	729
Trenton-crystalline interval	1,220	1,606

The Findlay well penetrated the crystallines 210 feet. The Waverly well did not penetrate the crystallines, though it probably reached them, since in the drillings from the very bottom of the well a few fragments from an igneous rock were obtained. Delaware is roughly halfway between Findlay and Waverly. If it is assumed that the Waverly well actually reached the pre-Cambrian, and if the average of the two Trenton-crystalline intervals at Waverly and Findlay (1,412 feet) is taken for Delaware County, the pre-Cambrian crystalline floor would be found 3,312 feet below the top of the Delaware limestone, and 2,472 feet below sea level.

Description of Formations

SILURIAN

MONROE FORMATION

The oldest and lowest bed-rock exposed at the surface in Delaware County is the Monroe dolomitic limestone.[2] This formation is from 400 to 600 feet thick in Ohio and occupies a wide north-south belt a little

[1]Bassler, R. S., The stratigraphy of a deep well at Waverly, Ohio, Am. Jour. Sci., Vol. 31, pp. 19–24. 1911.

Condit, D. D., Deep wells at Findlay, Ohio, Am. Jour. Sci., Vol. 36, pp. 123–130. 1913.

[2]Dolomite is used both for a mineral and a rock. The mineral dolomite is a carbonate of calcium and magnesium $(CaMg)CO_3$, containing 54.35 per cent calcium carbonate and 45.65 per cent magnesium carbonate. The rock dolomite, also called dolomitic or magnesium limestone, is made up of grains of the mineral dolomite. If it is without clayey or other impurities, which is almost never the case, its chemical composition will be that of the mineral dolomite. Usually it contains impurities which reduce the proportional amounts of the two carbonates, though not changing their relative amounts to each other.

Pure limestone is composed of the mineral calcite $CaCO_3$. Many limestones contain grains of both calcite and dolomite, and the proportions of the two minerals vary widely so that a series of rocks can be selected from those which are all calcite (ordinary limestones, calcite-limestones) to those which are all dolomite (dolomitic or magnesian limestones). Most limestones belong somewhere within this series and not at either end. The Monroe belongs near the dolomite end.

west of the center of the State. It occupies an area along the west side of the county, averaging five miles in width, its eastern boundary following a course a little east of north. The rock is nowhere today being quarried and exposures are infrequent and inconspicuous. Outcrops occur, none showing over eleven feet of rock, in the east bank of the Scioto where it enters the county, in the lower parts of Fulton and Bokes creeks, and more frequently in the banks of Mill Creek east to where the formation runs under stream level a mile west of Bellepoint.

Only the highest part of the Monroe is found at the surface in Delaware County where it shows two facies. One is a thin-bedded, very fine-grained and dense, gray or dove-colored dolomite in layers two to four inches thick. The other is a thicker-bedded rock, in beds reaching six to eight inches in thickness, of buff or brown color, more granular and porous than the thinner-bedded rock, and sometimes resembling the lower dolomitic part of the Columbus limestone to be described later. The rock is sometimes streaked and brecciated. Both facies are often found in the same exposure.

Fossils are absent or infrequent and occur mainly as hollow casts in the brown beds.

DEVONIAN

COLUMBUS LIMESTONE

General Statement.—The Columbus limestone, named from the excellent exposures in the great quarries at Marble Cliff on the Scioto west of Columbus, is the lowest of the Ohio Devonian formations and makes an irregular north-south belt in the western part of the county, east of the Monroe. The eastern boundary of the formation from the Franklin County line to the Springfield Branch of the Big Four is from one-fourth to one-half of a mile east of the Scioto, along the crest of the valley. Farther north it follows a northerly and poorly recognized course under the glacial drift to Marion County. There is also a three mile north-south belt west of the Scioto south from Bellepoint, and two smaller isolated areas south near the county line. The Olentangy River has cut through the Delaware into the Columbus at two places on the Dublin quadrangle, one for a distance of two miles northeast of Hyattsville, the other for two miles west of Orange. Excellent exposures are found along the Scioto and its tributaries south from White Sulphur. The rock has been quarried on a small scale at many places, and two quarries are now (1925) being worked on an extensive scale—that of the Scioto Lime and Stone Company, or the Klondike quarry, a mile southeast of White Sulphur on the east side of the Scioto, and that of the American Crushed Rock Company about a half mile southwest of White Sulphur.

Stauffer in Bulletin 10, Geological Survey of Ohio, pages 29–38, has divided the Columbus and Delaware limestones into a number of zones which are as follows:

	Average thickness Feet
Delaware limestone	
Zone M. Grayish or bluish brown limestone in layers of about six inches and containing some fossiliferous chert. This is the horizon which Winchell called "Tully limestone" and which Newberry conceded to contain a Hamilton fauna	10
Zone L. Granular grayish brown limestone, frequently made up to a large extent of the globular Coral, *Hadrophyllum d'Orbignyi*. It also contains many Brachiopods and occasionally abundant fish teeth. Iron pyrites often replaces the substance of the fossils	$\frac{1}{4}$
Zone K. Frequently containing much black chert and occasionally fairly massive layers of blue or brown limestone alternating with thin cherty layers. At the base it is often more or less contorted	11
Zone J. Usually a massive blue limestone with some thin or shaly layers and occasionally much black chert. It contains a great abundance of *Tentaculites scalariformis*	9
Zone I. Brown to bluish shale or thin-bedded shaly limestone with some black chert. To the north it becomes massive, but seems to retain its distinctive fauna of *Leiorhynchus limitare, Lingula manni, Orbiculoidea lodiensis, etc.*	6
Columbus limestone	
Zone H. Thin bedded to massive bluish-gray limestone. At the top it contains the "bone-bed," which has a thickness varying from several inches to a foot or more and is made up to a greater or less extent of the teeth, bones and dermal plates of fish. It also contains some fossiliferous gray chert which often occurs in layers. The zone contains many fossils, among which are especially to be mentioned, *Spirifer acuminatus, Nucleocrinus verneuili, Spirifer duodenarius, Paracyclas elliptica, Diphyphyllum verneuilanum*	10
Zone G. Massive gray limestone in beds from eight inches to three feet in thickness. Very fossiliferous and characterized by the occurrence in it of such large Cephalopods as *Gyroceras cyclops, Gyroceras Columbiense, etc*	22
Zone F. Massive gray limestone containing numerous fossils, but *Spirifer gregarius* exceedingly abundant, and usually referred to as the *Sp. gregarius* zone	5
Zone E. Massive gray limestone with an abundant fauna, but *Spirifer macrothyris* and *Strophonella ampla* are especially abundant	20
Zone D. Layers of gray chert alternating with layers of a sub-crystalline gray or brown limestone. Chert hard to chalky and very fossiliferous containing a great variety of Gastropods and many Brachiopods, Pelecypods, Corals and Bryozoa. The fossils usually have their exterior markings excellently preserved. This is the chert or Gastropod zone	8
Zone C. Brown limestone, quite massive, with numerous corals imbedded in it. At places it becomes a true fossil coral reef. Usually called the coral zone	4

	Average thickness Feet.
Zone B. Brown limestone, exceedingly massive, showing but few irregular bedding planes, and at places appearing as a solid wall without bedding planes. It contains much bituminous matter, has a saccharoidal appearance, and often shows a slightly banded structure.' The fresh surface of the rock sometimes glistens with cleavage faces of calcite and frequently contains pockets of the crystals. It also contains more or less chert scattered through the upper part. Fossils are usually rare and poorly preserved.	35
Zone A. Usually a conglomerate composed of water-worn pebbles of Monroe limestone imbedded in a matrix of brown Columbus limestone. Fragments of fossils are occasionally found, but northward the conglomerate ceases and the zone becomes very fossiliferous.	1

These divisions of Stauffer are based on differences both in rock character and in fossils. In so far as they depend primarily on differences in the fossils they cannot be recognized except by one who is acquainted with the fossils. Such a person will find Stauffer's divisions exceedingly useful. It seems desirable, however, in this bulletin, instead of using the eight zones, A–H, of Stauffer for the Columbus limestone, to separate that formation into four parts, easily recognized by physical characters, which are from above down as follows:

1. The Klondike member. A blue-gray, very fossiliferous limestone which makes the upper half of the formation. This is massive and thick-bedded where freshly quarried, but on weathered surfaces it is thin-bedded. The Klondike member includes Zones E (upper part) to H of Stauffer, and makes most of the Venice and Marblehead members of Swartz.[1] It seems best to use a local name for an easily recognized local subdivision which may not agree with subdivisions made at a distance. This division was called by Winchell[2] the Delhi beds, from the old name of Radnor. Most of the quarries in the Columbus limestone are in the Klondike member.

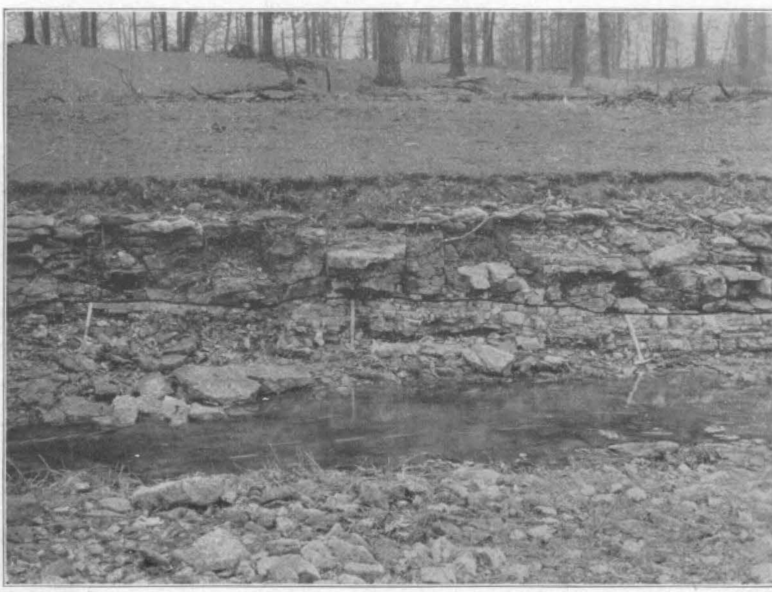
2. A heavy-bedded, fine-grained, brown-gray limestone, some six feet in thickness, showing marked conchoidal jointing in certain layers, with comparatively few fossils. A large brachiopod (*Spirifer macrothyris*) and a large coral (*Zaphrentis giganteus*) are characteristic of this layer. It is recognized by its fossils, by its more massive character compared with the layers both above and below, by its darker color and more granular character when freshly broken, and by its large-scale conchoidal joint fracture. It is the lower part of Stauffer's Zone E, and will be referred to as the *Spirifer macrothyris* zone.

3. The coral layer; a very fossiliferous brown limestone, especially rich in corals and stromatoporoids. Both the horn-shaped, simple coral

[1]Swartz, Charles K., The Relation of the Columbus and Sandusky Formations of Ohio. Johns Hopkins University Circular, New Series, No. 7, July, 1907, pp. 56–65.

[2]Geological Survey of Ohio, Vol. II., Report on the geology of Delaware County, p. 296. 1874.

A.—Quarry of the Scioto Lime and Stone Co. one mile southeast of White Sulphur. The Klondike member of the Columbus (40 ft.) shows, and a few feet of Delaware at the very top.



B.—Silurian-Devonian unconformity near Warrensburg. The black line marks the unconformity. Thin-bedded Monroe dolomite below; heavier Columbus (Bellepoint member) above.

forms and the larger branching or compact colony forms can be collected in abundance everywhere along its outcrop. This is Stauffer's Zone C.

4. The Bellepoint member; a massive, heavy-bedded, brown, nearly unfossiliferous magnesian limestone, conglomeratic at the base. This is well exposed in the cliffs along the Scioto below Bellepoint, and along lower Mill Creek. This includes Zones A (the conglomerate) and B of Stauffer, and will be referred to as the Bellepoint member, on account of the excellent exposures near that village. The name was first used by Swartz.[1]

The Klondike section.—The best exposure of the Columbus limestone in the county is at the quarry of the Scioto Lime and Stone Company, popularly known as the Klondike quarry. Half a mile south of the Springfield branch of the Big Four a small run enters the Scioto from the east; the quarry is an enlargement of the middle part of this ravine. The section is shown in Figure 6. The basal beds of the overlying Delaware limestone are found at the top of the quarry, and the section in the quarry and along the ravine to the river gives the whole Columbus formation except the lower fifteen feet which is below the level of the Scioto; but this lower part can be added on from a section of the lower part of the Columbus in the south bank of Mill Creek just east of the iron bridge a mile and a half west of Bellepoint. Here Mill Creek has cut through the Columbus into the underlying Monroe and a common bed, the coral layer, can be identified in each section. It is possible to combine them into a single complete section of the Columbus limestone—the last complete section in Ohio as one goes north along the outcrop of the formation. The total thickness of the Columbus is 80 feet, 9 inches, which is about 25 feet less than the Columbus at its type locality at Marble Cliff, west of the city of Columbus.

Other sections.—A mile west of the Klondike section, across the Scioto River, is the large quarry of the American Crushed Rock Company. The following is the section:

	Thickness Ft.	In.
Coral layer		
4 Gray limestone, in beds 2 to 4 inches thick	2	10
3 Gray, thin-bedded limestone	1	10
2 Gray-brown limestone, middle part shaly, in parts carbonaceous. Abundant stromatoporoids	2	10
Bellepoint member		
1 Heavy-bedded, brown, dolomitic limestone, some parts streaked with carbonaceous matter; several levels of chert nodules in the central part	21	6
Total	29	0

[1]Loc. cit. p. 63.

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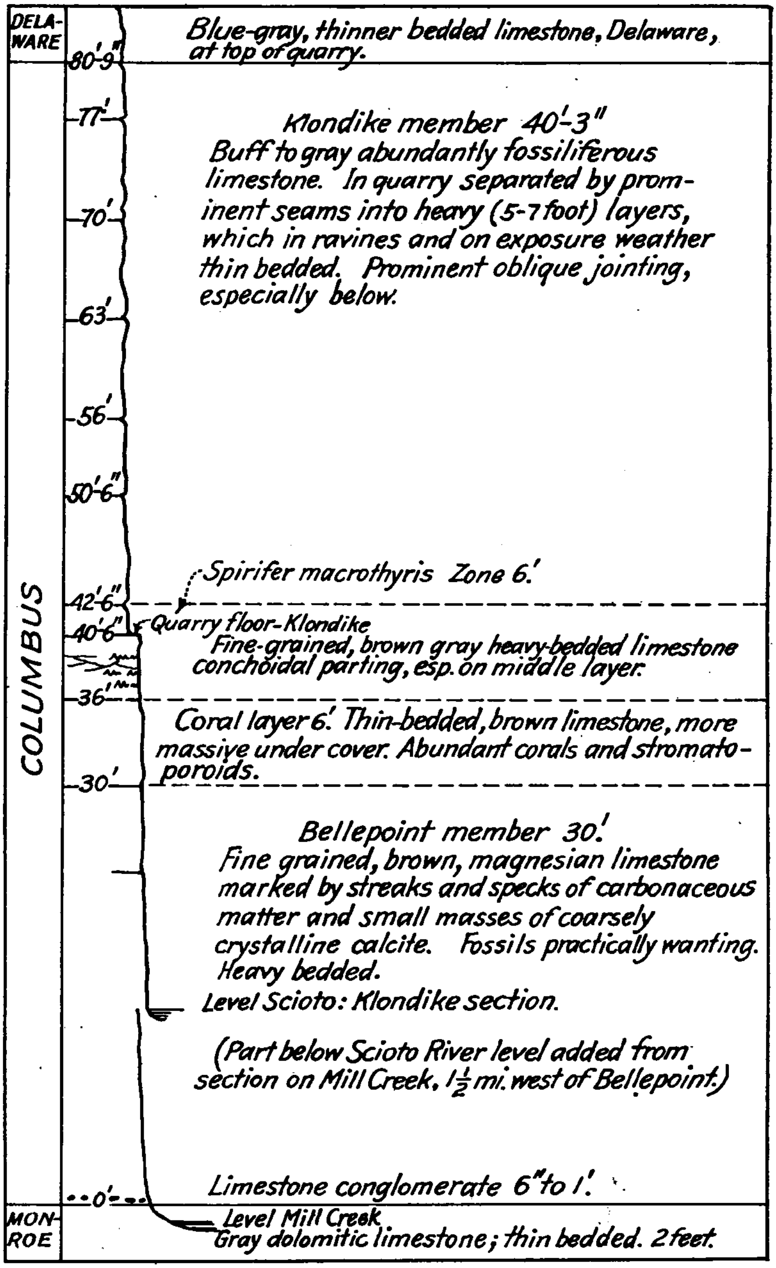

Fig. 6. Section of Columbus limestone at the quarry (Klondike) of the Scioto Lime & Stone Co., one mile southeast of White Sulphur.

The westward rise of the limestones brings them to higher levels in the White Sulphur quarry, so that the top of the working face here is the equivalent of the floor of the quarry in the Klondike section.

The character of the Columbus limestone changes somewhat in the southern part of the county. The following section was taken just north of the Franklin County line, at the O'Shaughnessy dam:

	Thickness Ft.	In.
6 Gray, well-bedded and thin-bedded very fossiliferous limestone. Weathers pitted. (Klondike member)	38	4
5 Same as No. 6. Heavier-bedded, in beds 2 to 3 feet thick	13	8
4 Heavy-bedded, gray-brown limestone, with several layers of chert nodules. Chert fossiliferous (Eversole chert)	2	11
3 Brown, bituminous cherty limestone, well-bedded; chert in nodules 2 to 4 inches thick and very fossiliferous (Eversole chert)	6	4
2 Brown, dolomitic limestone, streaked with carbonaceous matter, even- and heavy-bedded. Cherty. Chert not as fossiliferous as in No. 3	5	3
1 Brown, dolomitic limestone, streaked with carbonaceous matter. Massive and irregularly jointed, not distinctly bedded. (Bellepoint member)	9	6
Total	76	0

This section does not reach to the bottom of the Columbus, which is below river level. The top beds of the Columbus are shown on the side of the road, near the house, just southeast of the dam.

The following section in the Columbus limestone is taken in Eversole Run, a mile north of the O'Shaughnessy dam, between the road and the river, a section now largely under the reservoir level. It duplicates a part of the section at the dam.

	Thickness Ft.	In.
5 Gray, thin-bedded limestone, weathering to a pitted surface	7	0
4 Gray limestone breaking into layers 5 to 10 inches in thickness. Abundant corals and brachiopods	2	4
3 Gray limestone, blue-gray on fresh surface, breaking into irregular layers 4 to 6 inches thick. Abundant chert nodules in horizontal bands. Chert very fossiliferous	8	4
2 Brownish, dolomitic limestone, thinner-bedded than below. Some fossils. Reported by Stauffer as a mass of corals near the highway (coral layer)	5	4
1 Heavy-bedded, brown, dolomitic limestone. Fossils rare. (Bellepoint member)	12	6
Total	36	6

The most marked change in the section is the development of a conspicuous chert zone. The layer which contains the very fossiliferous chert (No. 3 of the Eversole section and Nos. 3 and 4 of the O'Shaughnessy dam section) is the Eversole chert, or Zone D of Stauffer. This lies just above the coral layer, and disappears to the north before White Sulphur is reached, where chert is almost absent at this level.

The base of the Columbus.—The lowest part of the Columbus is often a conglomerate, containing pebbles of fine-grained dolomite derived from the underlying Monroe formation. These are from less than an inch to four or five inches in diameter and commonly flattened. They are most abundant in the first few inches of the Columbus but may occur to a distance of between one and two feet above its base. The conglomerate can be seen at a number of places along the Scioto River and Mill Creek, but the best exposure is in the banks of a small stream entering the Scioto from the west a mile above Warrensburg.

At this same locality, which is about a half-mile west of the road, the unconformity, here angular, between the Monroe and the Columbus is best exposed. The rather uneven contact plane between the two formations cuts across the slightly bent beds of the underlying Monroe, as shown in the photograph, Plate IA.

The events recorded by these structural relations are as follows: After the Monroe dolomite had been formed and hardened it was raised above sea level, slightly folded, and subjected to erosion. How much dolomite was removed from above the present top of the Monroe during this period of emergence is not known. When the surface again sank beneath the ocean of that time the first waves of the Devonian sea rolled the rough limestone fragments lying on the surface until they were rounded and left them buried in the lowest lime muds of the Bellepoint beds of the Columbus. There is nothing to show, in this particular locality, how long a land interval the unconformity represents. But from the fact that the lowest Devonian beds of the county are of Middle Devonian age and thick beds of Lower Devonian time, which are found in eastern United States, are lacking, it is believed that this interval was long—was measured in terms of tens, possibly of hundreds of thousands of years.

The top of the Columbus.—The base of the Columbus is sharply separated from the underlying Monroe limestone and a long period of land emergence intervened between the two. In contrast with this, no period of land emergence separates Columbus from Delaware time. Through both periods the interior sea was in continuous existence; any physical break between the two is lacking. At the Columbus quarries a fairly easily recognizable bone bed, marked by small scattered teeth and plates of fishes, is taken to mark the top of the Columbus limestone. North, in Delaware County, the bone bed becomes less distinct. However, it usually can be found, especially with a little help from the imagination; but the practice in mapping the formations has been to draw the boundary at the top of the narrow

Spirifer duodenarius zone, which lies directly beneath the bone bed. The passage, which within a few feet is gradual, from the gray crystalline limestone of the Columbus to the blue finer-grained rock of the Delaware, helps. The disappearance of certain other species of fossils and the introduction of new forms also help. But the essential thing to note is that the transition from Columbus to Delaware was gradual. Indeed, it is doubtful if it is any more marked than certain transitions within both Columbus and Delaware. In a continuing shallow sea physical conditions and so conditions of life were rapidly but not abruptly changing. With unknown changes in the shore lines and in height of bordering land areas, the kind of sediment brought to this part of the sea changed. These changing bottom conditions, together with the possible opening of distant land barriers, influenced the kinds of life, and Columbus sediments and life gave place to those of the Delaware.

DELAWARE LIMESTONE[1]

The Delaware limestone, the highest formation of the great limestone series of western Ohio, is named from the quarries in that rock in Delaware. It forms a north-south belt (Map I) east of the Columbus outcrop with its eastern edge about at the Olentangy River. South of Stratford and west of the Olentangy the limestone is overlain by a poorly defined area of Ohio shale south to the county line.

The Delaware quarries section.—The type section (Fig. 7) of the formation is at the quarry in the south bank of Delaware Run, just east of the Hocking Valley Railway. Recent quarrying has gone below the earlier quarry floor into the upper layers of the Columbus limestone. In the section given, the upper layers, above the heavy, 18-inch chert bed, are described as found in the smaller quarries just west of the railroad.

The contact with the underlying Columbus is difficult to make out. The bone bed is practically absent and on the fresh surfaces at the bottom of the quarry it is hard to get fossil evidence. It is believed, however, that the contact as drawn is correct within a few inches of possible error.

The lower two-thirds of the quarry is the medium to heavy-bedded blue-gray limestone most characteristic of the formation. Several thin bands of brown, shaly limestone occur as partings. Numerous bands of chert nodules occur; the most conspicuous an 18-inch band twenty feet above the base of the formation. This is traced throughout the quarries and can be used in identifying the breaks or faults which cut the limestone. Two or three feet above this chert the character of the limestone changes. It is more variable, is on the whole thinner

[1]Prosser, C. S., The Delaware Limestone, Jour. Geology, Vol. 13, pp. 413-442. 1905.

bedded, and weathers light-brown. Layers of crinoidal limestone and one thin layer of bryozoan (*Stictopora*) limestone come in. In the quarry west of the railroad a local unconformity is found which truncates the underlying limestone. Above it is a thin-bedded crinoidal limestone, the basal layer of which is a bone bed, much more conspicuously furnished with fish fragments than is the bone bed at the Delaware-Colum-

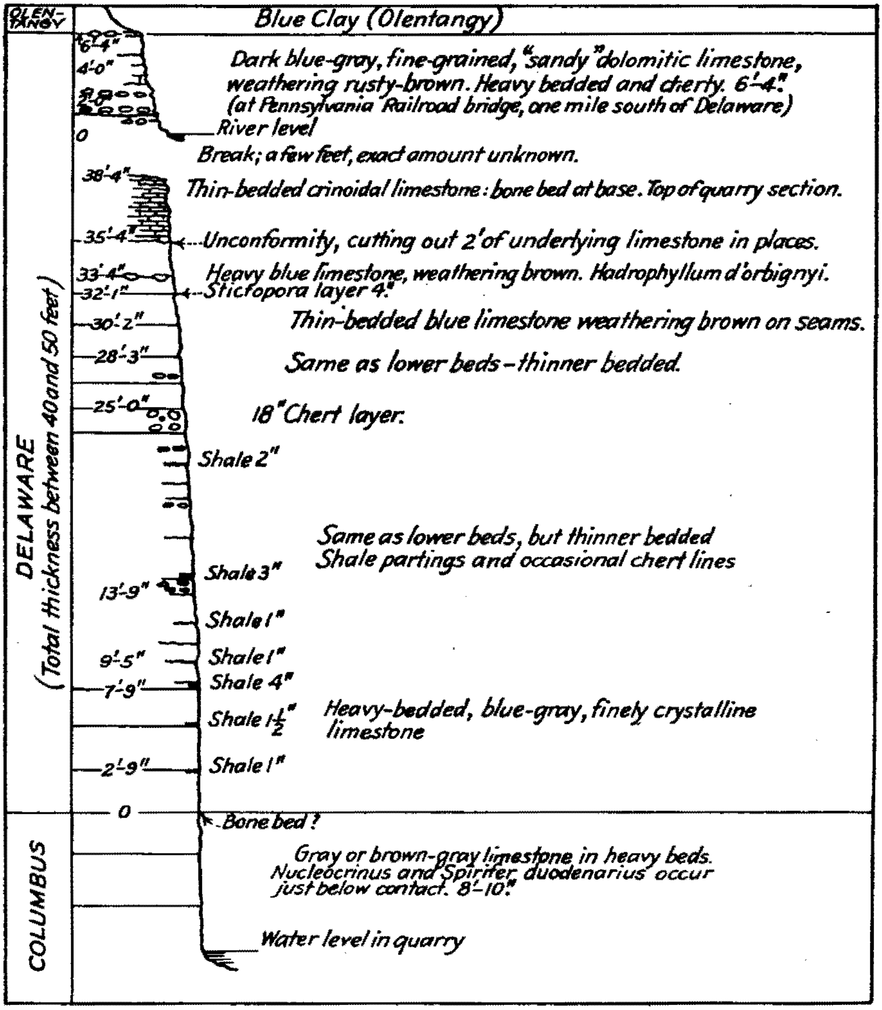

Fig. 7. Section of Delaware limestone in the Delaware quarries.

bus contact at any point in Delaware County. The unconformity proves very shallow water, perhaps even emergence near the close of Delaware time.

The very highest beds of the Delaware are not seen in the quarries at Delaware. They can be seen in the bed of the Olentangy River at the Pennsylvania Railroad bridge a mile south of the city where a heavy-bedded, dark, blue-gray, "sandy" limestone is found, weathering rusty-brown and containing chert concretions. Six feet four inches of these beds is found above river level, and, in the bank just east of the bridge, the Olentangy shale may be seen resting on the highest limestone layer. These rocks are added at the top of the section (Fig. 7). An estimated total of 45 feet would include the upper beds at the Pennsylvania Railroad bridge, and probably be very close to the actual thickness of the Delaware.

Other sections.—Ten miles south of Delaware a complete section of the Delaware limestone is shown in a ravine in the east bank of the Olentangy River a half-mile south of the Orange road. In following the rocks up the ravine it is necessary to use care to avoid error in measurement, on account of slight folding and faulting. The section is as follows:

	Thickness Ft.	In.
Delaware limestone		
7 Heavy-bedded, dark, fine-grained limestone weathering rusty brown. White chert is abundant in the upper layers. *Hadrophyllum d'Orbignyi* is found in a 20-inch layer eight feet below the summit......	10	8
6 Gray, shaly limestone........		11
5 Massive, cherty limestone layer........	5	
4 Gray, fine-grained, medium-bedded, limestone with several seams of chert........	8	10
3 Alternating layers of thin-bedded, brownish-gray limestone and dark chert........	8	
2 Heavy-bedded, blue-gray, fine-grained limestone........	6	7
Total Delaware........	40	0
Columbus limestone		
1 Heavy-bedded, gray limestone, abundantly fossiliferous, to stream level	20	

The bone bed is not recognizable, and the Columbus-Delaware contact is placed just above the *Spirifer duodenarius* zone.

The chief difference between the section here and at Delaware is in No. 3, which is absent at Delaware.

Eastward up the ravine a fair section of the Olentangy is shown, and farther east the Ohio shale.

The following section of the Olentangy shale and Delaware limestone is found along Bartholomew Run,[1] which enters the Olentangy from the west, a mile north of the Franklin County line, and is copied from Bulletin 14.

[1]Geological Survey of Ohio, Bull. 14, Geology of the Columbus Quadrangle, p. 23.

		Thickness
Ohio shale		
25	Black shale, rather thin bedded and considerably weathered. It contains a number of large spherical concretions	16′ 0″
Olentangy shale		
24	Soft bluish marly shale, the upper part yellowish in color	3′ 10″
23	Layer of flat, more or less disc-like, calcareous concretions	0′ 7″
22	Soft blue marly shale, with some brown layers	7′ 2″
21	Layer of impure bluish limestone	0′ 6″
20	Bluish marly shale, with some thin bands of brown or black shale	2′ 0″
19	Black shale, containing some fragments of fossil plants	0′ 7″
18	Marly blue shale	1′ 0″
17	Black shale cut into small blocks by two conspicuous systems of joints. Iron pyrites common	0′ 3″
16	Marly blue shale	1′ 8″
15	Two distinct layers of impure blue limestone	0′ 4″
14	Bluish green marly shale, containing thin bands of brown shale	2′ 4″
13	Brown shale with marl-filled marks, or trails of marine "worms." It also contains fragments of plants	0′ 3″
12	Soft bluish green marly shale, containing great numbers of small limestone concretions	5′ 0″
11	Brown shale with some "worm" trails through it, and containing a few bryozoans (?)	0′ 3″
10	Bluish green shale, soft and gritless, showing some trails of marine animals	2′ 4″
Delaware limestone		
9	Cherty blue to brown shaly limestone, the top of which is penetrated by the "worm" holes and filled with blue marl from above. Fish teeth and bones, somewhat water worn, and a few pebbles are also included in this shaly mass. At the present time this is the only known exposure of this contact	0′ 5″
8	Very cherty bluish brown limestone. Layers rather even and sparingly fossiliferous. This is the zone which Winchell called "Tully limestone," and which Newberry conceded to contain a Hamilton fauna.	9′ 4″
7	Granular layer of grayish brown limestone containing much iron pyrites which, in some cases, has replaced the original substance of the fossils. This thin zone contains a varied fauna notable among the species of which is the small globular coral, *Hadrophyllum d'Orbignyi*	0′ 8″
6	Massive bluish limestone containing very little chert	2′ 0″
5	Thin bedded shaly limestone with much black chert	1′ 0″
4	Blue to brown limestone containing iron pyrites and black chert intermingled and much contorted. These layers, together with the two just above, usually contain many specimens of *Grammysia bisulcata*	4′ 0″
3	Rather massive blue limestone with some chert and shaly layers. *Tentaculites scalariformis* is a common fossil	8′ 0″
2	Thin bedded brown calcareous shale with layers of black chert. It contains the Marcellus shale fauna	7′ 0″
1	Brown limestone, somewhat shaly and probably a part of the above zone. These layers extend to the level of the run below the highway bridge	2′ 6″

North from Delaware there are no good sections of the Delaware. At several places in the bed of the Olentangy River, east of Norton and

Waldo, a hard, blue crystalline pyritic and somewhat fossiliferous limestone is found, which apparently belongs to the upper part of the Delaware. Four miles north of the county line an old quarry in the east bank of the Olentangy shows ten feet of Delaware limestone and the river bed here is the same rock.

OLENTANGY SHALE

The Olentangy shale is a blue-gray, clay-shale, between thirty and thirty-five feet in thickness, named by N. H. Winchell[1] from its exposures along the Olentangy at Delaware. The outcrop in the county is limited to the Olentangy Valley. At the Delaware-Franklin County line it forms the bed of the Olentangy River and its surface is eight feet above river level in the cliff on the east side of the river. The rocks rise to the north so that within a half-mile the river is flowing on limestone and the Olentangy shale is found low in the eastern slopes of the valley, usually well shown in the side ravines. It drops to river level again a mile below Delaware where it makes the lower part of the shale banks north and south of the city. Going north, it is seen for the last time at the bend of the river east of Troy, beyond which to the Marion County line it lies west of the river, concealed beneath the glacial drift. The Olentangy is found beneath the Ohio shale in a number of the ravines west of the river from the Franklin County line nearly to Stratford. As the rocks rise to the west there should be a second line of outcrop where the Olentangy comes out from under the Ohio on the west. This line of outcrop is completely concealed by the overlying glacial drift; it is mapped with no attempt at accuracy, perhaps not even approximately, as a north-south belt, a little west of Hyattsville and Powell.

The shale is a soft, blue-gray, gritless rock. It is not laminated; though when freshly dug it shows an indistinct bedding, the layers 3 to 6 inches thick. The exposed surface crumbles to small, flattish, angular debris, finally weathering to a gray clay.

Composition of Olentangy shale

The composition of the Olentangy shale at Delaware is shown below, and for comparison an analysis of the same formation from near Bainbridge, Ross County (Prof. D. J. Demorest, analyst):

	Delaware	Near Bainbridge
Silica, SiO_2	57.22	63.03
Alumina, Al_2O_3	16.15	16.56
Ferric oxide, Fe_2O_3	4.78	5.62
Lime, CaO	3.71	1.10
Magnesia, MgO	2.31	1.56

[1]Geol. Survey Ohio, Vol. II, p. 287.

	Delaware	Near Bainbridge
Titanic oxide, TiO_2	1.26	0.88
Sodium oxide, Na_2O	0.16	0.40
Potassium oxide, K_2O	3.86	4.05
Manganous oxide, MnO	0.016	0.06
Phosphorus pentoxide, P_2O_5	0.099	0.10
Barium oxide, BaO	0.00	......
Moisture at 105° C	1.21	0.03
Ignition loss	8.02	7.14
Sulphur	0.96	1.16
	99.755	101.69
Inorganic carbon, C	1.00	0.51
Total carbon, C	1.69	1.08

A sample of the Olentangy shale from Delaware was submitted to Prof. W. J. McCaughey of the Ohio State University for microscopic study and his comments follow:

When moistened with water and rubbed with the thumb to disintegrate and deflocculate the mass, the Olentangy shale gives in water a gray silvery suspension somewhat similar to that of fine-grained mica, or to that of crystalline kaolinite in water. Silky suspensions are also produced in fine-grained crystalline precipitates and are probably due to the reflection of light from the faces of the crystals.

The sample was separated by deflocculation and decantation to yield a sand separate, two silt separates, and a clay separate, which were examined separately.

The sand separate was small in amount, a per cent or two, and consisted predominantly of a carbonate mineral of the calcite series, generally in rhombohedral crystals. The index of refraction of the ordinary ray of this mineral was slightly less than 1.680 which indicates that the mineral has a composition rather close to dolomite.

The rhombohedral aspect of the crystals is also a characteristic habit of dolomite. Sometimes this dolomite is a fine-grained aggregate often with nearly parallel orientation. In the heart of the dolomite particles is a core of pyrite generally in tiny crystals (cubes and cubes modified by octahedrons). Pyrite also occurs free as crystals. A smaller amount of quartz is present and occasionally a cleavage fragment of muscovite.

The silt separate forms a large part of the sample and carries abundant dolomite grains as rhombohedral crystals and as separate grains composed of aggregates of finer crystals of dolomite. A fairly large amount of muscovite and sericite is present. Pyrite is also found in considerable amount either as separate crystals or imbedded in or attached to dolomite. In smaller amount, well rounded and clear fragments of primary quartz occur, though most of the quartz is present as a very fine-grained mineral free or imbedded in a sericite-clay-quartz aggregate.

The dolomite is generally free as rhombohedral fragments, sometimes attached to the clay aggregates but not frequently enclosed in them. The clay aggregates, though generally free from enclosed dolomite, carry abundant inclusions of sericite and fine-grained quartz; also in smaller amount rutile as very tiny needles; and tiny rounded particles, more or less opaque and difficult of determination—probably iron oxide or partially oxidized pyrite.

Rarely grains of tourmaline and still more rarely zircon and rutile are found. An occasional grain of biotite is present, stained red by iron oxide.

The clay separate is a fine-grained aggregate composed of kaolin with abundant sericite and finely divided quartz and a much smaller amount of rutile as tiny needles.

A.—Olentangy shale, Delaware. The dark band half way up the cliff marks the junction with the overlying Ohio shale. Concretionary limestone layers of the Olentangy show in the foreground.

B.—Olentangy shale interbedded in the Ohio. The clayey masses are the Olentangy; the harder projecting layers the Ohio. Note the blocky character of the Ohio shale in the bed of the stream, proving deepening of channel by plucking.

The minerals, as separate grains of the Olentangy shale, in order of their abundance are dolomite, pyrite, sericite, quartz, and muscovite; more rarely tourmaline, biotite, zircon, and rutile. In the clay aggregates the minerals are kaolin, sericite, quartz, and rutile.

An outstanding characteristic of the sample lies in the large amount of free (unattached) crystals of dolomite and of pyrite, the latter often enclosed in the dolomite or attached to it. A large part of the quartz is very finely divided and is present in the clay aggregate. The high content of sericite is noteworthy and the comparative freedom of the small clay aggregates (broken in preparation of sample) from dolomite.

The silky character of the suspension of the Olentangy shale is probably due to the presence of the minute and free crystals of dolomite and to sericite and muscovite held in water suspension.

Figure 8 is a section of the Olentangy at the type locality in the east bank of the Olentangy at Delaware, just south of the city limits. The section is taken at the south end of the cliff. The very lowest part of the formation is below river level. The upper surface of the Delaware limestone shows just west at the Pennsylvania R. R. bridge, and a careful calculation of the drop of the limestone places it three feet below river level at the point where the section is taken.

Two exceptional features are shown in the section: certain thin, dark shale bands in the upper part, and layers of limestone concretions and of concretionary limestone, found more abundantly in the lower part of the formation. The limestone concretions are considered (p. 53) in the general discussion of concretions. The shale bands resemble the overlying Ohio shale in physical character and like the Ohio shale contain abundant minute plant spore cases. These thin layers represent brief periods of black mud sedimentation in advance of the main black mud sedimentation of Ohio shale time. A second section of the Olentangy shale, on Bartholomew Run, is given on page 30.

The base of the Olentangy presents an absolutely abrupt change from the underlying Delaware limestone. At the Pennsylvania R. R. bridge typical blue clay of the Olentangy lies directly on the massive limestone of the upper Delaware. The top of the Delaware is the upper surface of a single limestone layer; there is no structural evidence of an unconformity. On a larger view of the two formations, however, it is found that south of Delaware County the Olentangy rests in succession on the Delaware, the Columbus, the Monroe, and even, in Ross County, the Niagara, proving an unconformity at the base of the Olentangy.

The top of the Olentangy is a sharp transition from the blue clay of the Olentangy to the dark, slaty Ohio shale. At the type locality in Delaware the contact is slightly undulating. This is due in part to gentle warping of the rocks, partly to displacement of the contact plane by the growth of large limestone concretions in the shale just above. The bedding in both rocks adjacent to the contact is parallel to the contact. The structural relations are those of conformity. A

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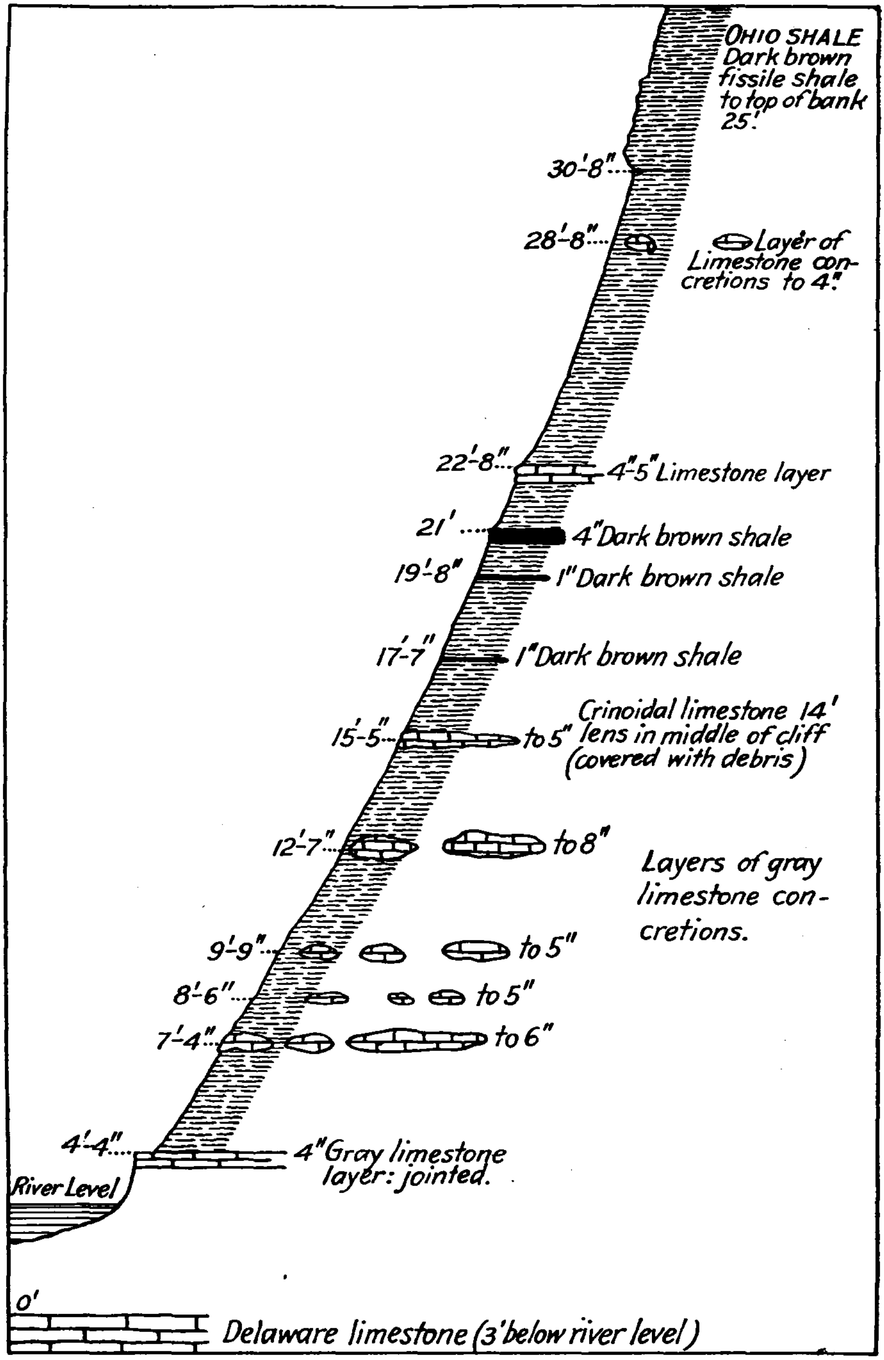

Fig. 8. Section of Olentangy shale along Olentangy River just below Delaware. Plate II A is a photograph of this section.

strong additional reason for conformity is found in the layers of dark shale in the upper part of the Olentangy which have all the characters of the Ohio shale; and in the further fact that layers of blue-gray clay, indistinguishable from the Olentangy, often repeated and several feet in thickness, are in places found well up in the Ohio shale. See Plate II B.

Fossils are exceedingly rare in the Olentangy shale. In the brown shale bands are found fragments of plants and abundant plant spore cases. Stauffer[1] says that at Bartholomew Run, a mile north of the Franklin County line, "Aside from the plant remains and a few worm trails, little in the way of fossils was collected. A fragmentary Pelecypod of undetermined genus, but probably a *Nucula,* a single Crinoid segment, and a probable Bryozoan constitute the entire collection." At the type locality at Delaware Stauffer[2] reports

Melocrinus sp.
Leiorhynchus sp.
Orbiculoidea sp.
Pleurotomaria sp.
Orthoceras sp.

There is also in the section at Delaware, 16 feet below the top of the formation, a lens of limestone containing abundant fragments of crinoids.

Stauffer[3] and Grabau[4] hold different views as to the relations of the Ohio and Olentangy shales. Stauffer believes that they are conformable, Grabau that they are not.

Stauffer bases his argument in part on the physical relations of the two formations as seen in Delaware and Franklin counties. These, however, as noted above, do not seem to favor unconformity. But Stauffer's main argument rests on the correlation of the Olentangy of central Ohio with some thirty-five feet of fossiliferous blue shales found a few miles southeast of Sandusky where the section is, from above down:

	Thickness Ft.	In.
4 Ohio shale	4	0
3 Encrinal limestone (Prout limestone), a hard blue limestone	8	10
2 Covered	6	0
1 Blue shales and interbedded limestones, at certain levels abundantly fossiliferous	28	6

[1]Stauffer, C. R., The Middle Devonian of Ohio, Geol. Survey Ohio, Fourth Series Bull. 10, p. 79.

[2]Stauffer, loc. idem, p. 89.

[3]Stauffer, C. R., The relationships of the Olentangy shale and associated Devonian deposits of northern Ohio, Jour. of Geology, Vol. 24, pp. 476–487, 1916.

[4]Grabau, A. W., Age and stratigraphic relations of the Olentangy shale of central Ohio, with remarks on the Prout limestone and so-called Olentangy shales of northern Ohio, Jour. of Geology, Vol. 25, pp. 337–343. 1917.

Below this section, but not shown at this locality, would come the Delaware and Columbus limestones.

Stauffer's grounds for the correlation of the blue shales in the above section with the Olentangy shale of central Ohio are in part the lithological resemblance of the two formations; in part the supposed agreement of the very scanty fauna of the Olentangy shale of central Ohio with that of the beds (No. 1 of above section) near Sandusky.

The blue shales of the Sandusky region Stauffer also correlates with certain Middle Devonian shales at Arkona in southwestern Ontario. The two shales are closely alike, both in rock character and fossil content. But in Ontario, instead of eight feet of limestone between the shales and overlying black Ohio shale, there are some 200 feet of Middle Devonian shales and limestones between the two.

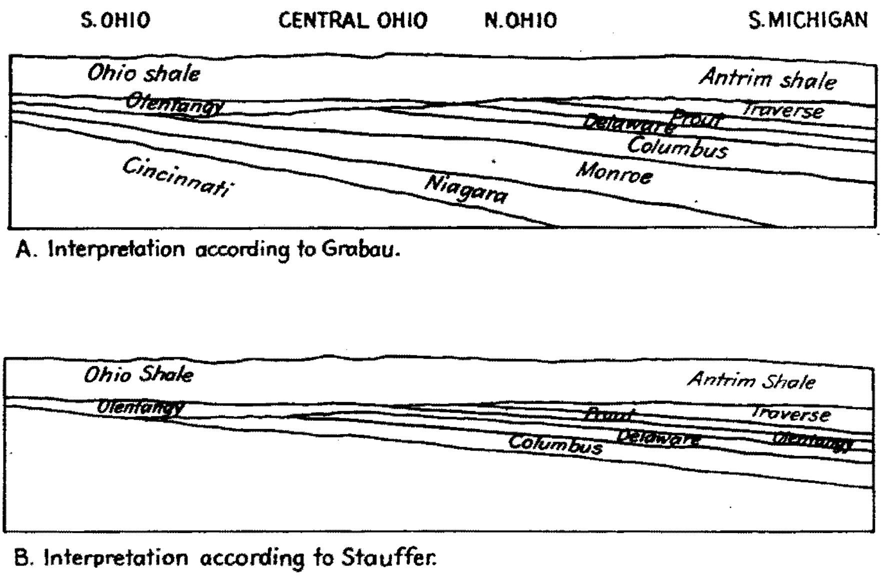

Fig. 9. Diagrams showing different interpretations of Devonian rocks according to Grabau and Stauffer.

Grabau accepts the identification of the fossiliferous blue shales and overlying Prout limestone of the Sandusky region with the shales and Encrinal limestone at Arkona. He does not, however, admit the correlation of the Sandusky blue shales with the barren Olentangy blue shale of central Ohio. He believes that the Olentangy is a local basal facies of the Devonian shale series of central Ohio, conformably underlying the black shale beds which make up the Ohio; that it runs out before reaching northern Ohio; and that this shale series, with a blue shale base (Olentangy) in central Ohio and a black shale base to the north (Ohio), rests, on going north, on successively higher Middle

Devonian beds—on the Delaware limestone in Delaware County, on the succeeding shales and Prout limestone near Sandusky, and on beds some 200 feet higher at Arkona. These higher beds disappear in succession going south because of erosion during the Middle Devonian pre-shale interval. The two interpretations of Grabau and Stauffer are shown in Fig. 9. In this bulletin an unconformity is placed at the base of the Olentangy and the Ohio is considered to rest conformably on the Olentangy shale. Hence Grabau's interpretation is accepted.

OHIO SHALE

General statement.—The Ohio shale has the largest surface exposure of any of the formations of the county, approximately one-third of its whole area, and makes a north-south belt between the Olentangy River on the west and Little and Big Walnut creeks on the east. The west boundary lies along the east side of the Olentangy, except for an isolated area west of the river in Liberty Township and a westward extension near the Marion County line, both largely concealed by glacial drift. The east boundary lies east of Little Walnut Creek from the Morrow County line to Galena, from there south in the east bank of the valley of Big Walnut Creek.

Good exposures of the base of the formation are shown in the cliffs on the east side of the river at Delaware and near the Franklin County line, and in nearly every ravine entering the river from the east. The middle beds are shown in many high cliffs along Alum Creek, one of the most picturesque where it is crossed by the Delaware-Sunbury road. The upper part shows in many exposures along the east side of Big Walnut Creek, south from Galena.

It is not possible to determine the thickness of the formation in Delaware County from surface exposures, as no complete sections occur and uniformity of the rock at separate localities makes it impossible to piece out a continuous section. If deep well records were available for the eastern part of the county they would give it, for they would go through the whole thickness of the Ohio; but for the few wells put down the records have not been kept. It is reported in the Columbus area[1] from well borings to be 600-650 feet thick. As the formation increases to the north, it probably is not less than 650 feet thick in Delaware County. In the columnar section it is placed at that figure.

The fresh rock is a dense, fine-grained, deep chocolate-brown or brownish-black shale, slightly gritty, indistinctly but thinly laminated. When freshly broken it has an oily smell. On quarrying it breaks into thin slabs; on exposure these become gray in color and break into thin plates. The surfaces and joints of the rock are usually iron stained.

Occasional thin bands of harder rock occur, one to two inches in

[1]U. S. Geol. Survey, Columbus Folio, p. 6.

thickness. Their hardness is due to the later deposit of calcite and quartz (chalcedony) in the band. Layers of limestone two to four inches thick, having cone-in-cone structure, are shown in the exposures along Alum Creek. Large concretions of dark limestone, sometimes six or more feet in diameter, are found in the lower part of the shale along the Olentangy but they are not found farther east in the middle and upper parts of the formation. They are described in the discussion of concretions, page 53. The bent shales around these concretions are the cause of the domings or basins in the shale in the floor of the ravines cutting the lower part of the formation; if a dome, the concretion is below, if a basin, it has been removed by the stream.

Below is an analysis of the Ohio shale,[1] from the Columbus Sewer Pipe Company's plant, North Columbus. Analyst, William McPherson.

Silica, SiO_2	58.38
Alumina, Al_2O_3	20.89
Water (combined), H_2O	7.53
Ferric oxide, Fe_2O_3	5.78
Lime, CaO	.44
Magnesia, MgO	1.57
Potash, K_2O	4.68
Soda, Na_2O	.34
Total	99.61
Fluxing impurities	12.81
Clay and sandy impurities	86.80

Life. — The most abundant, though not the most conspicuous fossils in the shale, are minute plant structures, possibly spore cases (*Sporangites huronensis* Dawson). They can be seen easily with a hand lens as minute brown discs almost covering the surface of many shale blocks. Other minute plant forms have been described by White and Stadnichenko[2] from the Ohio shale in Kentucky. They will probably be found also in Ohio.

Among larger plants are jointed, reed-like stems of *Calamites* to three inches in diameter, pointing to stalks 10 to 20 feet in length. Pieces of coniferous wood are found, sometimes in the large limestone concretions in the shale, sometimes in the shale itself.

Invertebrate fossils are rare: they include the brachiopods *Lingula* and *Orbiculoidea*, and small conodonts, to be seen with the hand lens, which are possibly the teeth of worms. In the concretions fragments of crinoids and poorly preserved brachiopods have been found.

[1]Geological Survey of Ohio, Vol. VII, p. 133.
[2]White, D., and Stadnichenko, T., Some mother plants of petroleum in the Devonian black shales, Econ. Geol., Vol. 23, pp. 238–252. 1923.

A.—Ohio shale, Alum Creek.

B.—Concretions in Ohio shale. Note how the shale curves over the concretions. In many places the shale may be seen also curving under the concretions.

Origin of the shale.—The origin of the extensive Devonian black shales is not certainly known. Newberry[1] compared the Devonian sea in which the Ohio shale was formed to the Sargasso Sea of the North Atlantic.

"Here, as in the other similar sheets of sea weed, the vegetation floats upon the surface of the water and maintains a vigorous and luxuriant growth without connection with shore or bottom. Corresponding to this growth must be the decomposition of vegetable tissue on a large scale. The products of such decomposition would fall to the ocean bottom as finely comminuted carbonaceous mud, mingled with stems and fronds detached by violence or decay. Under all such sheets of vegetation, in a sea where fine mechanical sediment is being deposited, we must necessarily have an accumulation of mud containing a large percentage of carbonaceous matter; in other words, the elements of a bituminous shale. Waiting the demonstrative solution of the problem, which patient and exhaustive study will doubtless sometime furnish, I offer, as a possible explanation of the peculiar features of the Huron (Ohio) shale, the suggestion that its carbon was derived from vegetation which lined the shores and covered the surface of a quiet and almost land-surrounded sea."

Recent explorations have shown that the so-called Sargasso Sea of the North Atlantic is not as important as earlier supposed; that the amount of floating vegetation is inconsiderable.

Grabau[2] has suggested that the Ohio shale consists of black organic muds washed into the sea which covered central and eastern Ohio from adjacent lowlands which were covered with fine black organic soils, perhaps resembling those of the Black Earth district of southern Russia. We are at any rate short of the demonstrative solution of the problem anticipated by Newberry.

MISSISSIPPIAN

BEDFORD SHALE

The Bedford shale makes a north-south belt east of the Ohio shale, crossing Big Walnut Creek at Sunbury. The contact with the underlying Ohio is seen on Little Walnut Creek below Lott school, on the Big Walnut at Galena, and in all the larger ravines on the east side of the Big Walnut for the four miles north of the Franklin County line. The upper contact with the Berea was not seen north of Sunbury, but is seen at frequent intervals south to the county line.

The Bedford is a soft, gritless, laminated, argillaceous shale of gray or brownish-red color, weathering to a red or yellow clay. The most striking exposures of the formation are south of the county line, opposite Central College, where the Bedford makes the conspicuous gullied or "badlands" slope of the Big Walnut Valley for two or three miles.

[1]Geological Survey of Ohio, Vol. 1, part 1, p. 156. 1873.
[2]Grabau, A., Textbook of Geology, part 2, pp. 408–411. 1921.

Composition of Bedford shale

A sample of Bedford shale from Galena, Delaware County, was submitted to Prof. D. J. Demorest for analysis, and his results follow:

Silica, SiO_2	57.76
Alumina, Al_2O_3	18.58
Ferric oxide, Fe_2O_3	7.45
Lime, CaO	.55
Magnesia, MgO	1.33
Titanic oxide, TiO_2	1.50
Potassium oxide, K_2O	3.51
Sodium oxide, Na_2O	.52
Manganese oxide, MnO	.018
Phosphorus pentoxide, P_2O_5	.114
Barium oxide, BaO	tr.
Sulphur, S	.029
Moisture at 105° C	1.44
Ignition loss	6.46
	99.261
Total carbon, C	.71
Inorganic carbon, C	.30

A sample was also submitted to Prof. W. J. McCaughey for microscopic study. His results are given below:

The sand and coarse silt separate contain abundant quartz and undisintegrated clay aggregates with a smaller amount of dolomite (index higher than 1.67) in aggregates, also muscovite, chlorite, sericite, and biotite (latter deep red or yellow in color). Tourmaline, zircon, and rutile are also present, but are not abundant.

The finer silt and clay separate contain abundant sericite and quartz and a smaller amount of dolomite, the latter generally free or unattached. There is also present occasional cleavage flakes of muscovite, biotite, and chlorite.

The clay is a quartz-sericite-kaolin aggregate carrying tiny needles of rutile and red to yellow particles of iron oxide. The abundant sericite in the clay aggregate and in the clay separate is noteworthy; also the constant association of bright green cleavage fragments of chlorite, and the abundance of muscovite in the coarser separates.

In the Bedford the quartz has a higher concentration in the coarse separates (sand and coarse silt) and occurs in much larger fragments than in the Olentangy examined. (Page 32.) The Bedford contains more mica in larger cleavage fragments (muscovite, biotite, and chlorite), than was found in the Olentangy. The clay aggregate in the Bedford is more complex, mineralogically, and carries more iron oxide than the Olentangy.

As separate grains, the minerals in order of their abundance are quartz, sericite, dolomite, muscovite, chlorite (bright green flakes), biotite (somewhat altered, yellow or deep red), tourmaline, zircon, and rutile. In clay aggregates the minerals in order of their abundance are kaolin, sericite, quartz, iron oxide, and rutile.

The following section[1] of the Bedford and overlying formations was taken along Duncan Run:

	Thickness
Cuyahoga formation	
11 Blue to gray sandstones in layers from a few inches to six or eight in thickness	5′ 0″
10 Bluish gray shale, alternating with shaly sandstones, the surface of which shows some marks resembling impressions of plant stems or trails of animals	10′ 0″
9 Gray shale, not well exposed	5′ 0″
Sunbury shale	
8 A fissile black shale. The contact with the Berea grit is shown back of Harlem, but the contact with the Cuyahoga formation is slightly covered	30′ 0″
Berea grit	
7 Buff to bluish gray fine grained sandstones, the upper layer much iron stained. The lower layers are rather thin shaly and well ripple-marked. At Harlem this stone has been quarried and crushed for road material; for which purpose, when mixed or covered with crushed limestone, it is said to serve excellently. In the quarry here it is a fine-grained bluish sandstone, rather compact and often banded	40′ 0″
Bedford shale	
6 Mottled and gray argillaceous shales, with some sandy layers	28′ 6″
5 Soft red or chocolate brown shales	16′ 0″
4 Gray shales with a few thin layers of chocolate brown shale	12′ 4″
3 Layer of very compact hard red or chocolate brown shale	0′ 4″
2 Soft gray argillaceous shale containing fossils in the lower part	2′ 10″
Ohio shale	
1 Firm black shale to level of Big Walnut Creek	55′ 0″

BEREA[2] SANDSTONE

The Berea sandstone crosses the county in a north-south belt from one to two miles in width. As it is a harder rock than the shales to the west it makes about 100 feet higher ground.

The rock is a medium to fine-grained sandstone. The beds are distinctly cross-bedded at low angles and many of the layers show ripple marks, both features evidence of shallow water conditions. No fossils are found in the formation in the county. A peculiar irregular "concretionary layer" is found in the formation at Sunbury the origin of which is not understood.

The best exposures are found along the Big Walnut near Sunbury and south to the county line in the ravines coming in from the east.

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[1]Geological Survey of Ohio, Bulletin 14, Geology of the Columbus Quadrangle, p. 31.

[2]The thickness of the Berea is given as 40 ft. on Duncan Run and 65 ft. on Rattlesnake Run. At Gahanna, Franklin County, it is 30 ft. This last value is the one given in Fig. 4.

The following section[1] was taken along Rattlesnake Creek east of Sunbury:

	Thickness
Cuyahoga formation	
12 Soft blue shale, composing the base of the formation	5′ 0″
Sunbury shale (total thickness, 17 ft.)	
11 Meager outcrops of bituminous black shale, somewhat iron stained	12′ 0″
10 Partly covered interval of black shale	5′ 0″
Berea sandstone (total thickness, 64 ft. 8 in.)	
9 Rather thin bedded gray to buff sandstone. The upper four-inch layer contains a great deal of sulphide of iron (aneroid reading)	25′ 0″
8 Fairly thick layers of sandstone showing a lenticular shape and interbedded with thin layers	15′ 0″
7 Concretionary masses of sandstone with thin shaly layers, all more or less disturbed	5′ 0″
6 Ripple-marked thin shaly sandstone layers, somewhat banded	5′ 0″
5 Rather massive layers of sandstone interbedded with some shale. The massive layers are more or less concretionary	5′ 0″
4 Soft arenaceous shale containing some concretions	6′ 8″
3 Layer of massive concretions more or less continuous, but sometimes interrupted and apparently somewhat replaced by the bluish shale	3′ 0″
Bedford shale	
2 Bluish gray shale, which is rather argillaceous, but somewhat gritty	2′ 0″
1 Covered to level of Big Walnut Creek	5′ 0″

The Berea has been traced across the State from Lake Erie to the Ohio River. North at Berea and Amherst it is a well-known source of building stone. Small quarries have been opened near Sunbury, but none are now working, and it is of little value in the county.

The Berea is unconformable on the underlying Bedford. In the northern part of the State[2] it fills deep channels in the Bedford. It is in these old channel fillings, where the total thickness of the sandstone sometimes reaches 100 feet, that the large quarries are located. At Lithopolis, in Fairfield County, the unconformity is well shown. It is not distinctly shown in Franklin and Delaware counties.

The contact of the Berea with the overlying Sunbury black shale is perfectly sharp, the fine black shale in typical development resting directly on the massive sandstone.

SUNBURY SHALE

The Sunbury shale[3] lies immediately above the Berea sandstone and makes a north-south belt across the county just east of that of the Berea. The formation was named from poor exposures on Rattlesnake Creek, 2½ miles east of Sunbury. Much better sections are found south in Franklin and Fairfield counties.

[1]Geol. Surv. Ohio, Bull. 14, p. 33.

[2]Burroughs, W. G., The unconformity between the Bedford and Berea formations in northern Ohio, Jour. Geol., Vol. 19, pp. 655–9. 1911.

[3]Prosser, C. S., The Sunbury shale of Ohio. Jour. of Geol., Vol. 10, pp. 262–312. 1902. This paper gives a detailed account of the Sunbury shale in the State.

The rock is a black, bituminous, shale, uniform in character vertically and horizontally, breaking into thin plates. Samples from Gahanna, five miles south of Delaware County, gave 11 gallons of oil to the ton of shale.[1] Small exposures are found east of Olive Green, near Sunbury, on Perfect and Rattlesnake creeks, and on Harlem Run. For long distances no outcrops at all are found and the mapping of the formation is of necessity approximate only, largely determined by the relief of the adjacent Berea. No sections are found in Delaware County which give the thickness of the formation. At Lithopolis, in Fairfield County, it is 30 feet thick.

Where the base of the shale is seen it is in abrupt contrast with the underlying Berea, marking a sudden change in sedimentation from a clean sand to black bituminous mud. A sharp change in character separates it as well from the overlying Cuyahoga sandy shales.

In certain layers of the shale in Franklin County small brachiopods, *Lingula melie* Hall and *Orbiculoidea newberryi* (Hall), are common.

CUYAHOGA FORMATION

The highest formation in Delaware County is the Cuyahoga, a series of gray, sandy shales and thin, fine-grained sandstones, with occasional thicker layers of sandstone. It makes a belt three to four miles in width along the eastern edge of the county, reaching a probable thickness on the county line of something over a hundred feet. The valleys here are shallow and rarely cut through the drift to the underlying Cuyahoga. Nor has it at any time been quarried and used.

The Lost Interval

Resting on the different bed-rock formations of the county, is the boulder-clay, of glacial origin. The bed-rocks are marine formations laid down when the county was beneath the waters of an inland sea. The boulder-clays are deposits on land made by the continental ice sheet. It is clear that at some time after the deposition of the latest bed-rock formations, crustal uplift brought the sea bottom above the surface of the sea, inaugurating a land era which has lasted to the present time. River erosion bevelled off the inclined rock formations, bringing different ones to the surface, and, at a later time, the southward spread of the Canadian ice sheet into Ohio laid down the boulder-clay mantle-rock. This interval between the deposit of the latest bed-rock sediments and the glacial boulder-clay is the lost interval, an interval not represented locally by any rock formations.

It was a long interval. Estimates of geological time in years are never accurate, and they vary widely as made by different geologists and

[1]Ashley, Geo. H., The oil resources of the black shales of the eastern United States, U. S. Geol. Surv. Bull. 641-L, p. 319. 1917.

from different data. Recent estimates, based on radioactive changes of minerals in rocks, appear at present to be more accurate than earlier estimates based on other evidence; they certainly are longer. Barrell's[1] estimate would make the time of the Devonian over 300,000,000 years ago. The age of the Wisconsin glacier again is differently dated by different geologists—perhaps 50,000 years back would be a fair average estimate of the time of the maximum development of the Wisconsin glacier. The lost interval then would be the difference between the two figures—nearly 300,000,000 years, a very long time. Suppose it were only a half or a quarter as long, geological friends with unlimited time at their disposal will not fight over any such paltry matter as a few million years. In any case the lost interval was long.

For the record of what happened during this interval it is necessary to go outside of our local area. At some time after the Devonian, probably before the end of the Paleozoic, central Ohio finally emerged from beneath the waters of the interior sea. Somewhat later came the Appalachian revolution, one of the times of great crustal movement of the earth's history, when the Paleozoic rocks, along a belt from the St. Lawrence to Georgia and Alabama, were thrown into a series of great folds with high relief. These folded rocks are now found to the southeast, in eastern and central Pennsylvania and on the borders of Virginia and West Virginia. That region was then an area of mountainous relief, certainly much higher than today. But west of this mountain area of intense folding, and indeed throughout the continent generally, uplift took place; though it was characterized by less elevation and by gentle warping rather than sharp folding.

A long period of stream erosion began, of which only the later stages are known for Ohio. The main part of the State was finally reduced to a nearly level plain, not far above sea level (a peneplain). The only exception to the almost perfect plainness of the surface was where formations of harder rock, inclined slightly to the southeast, made belts of slightly higher country rising gradually from the east to low westward-facing escarpments, one or two hundred feet above the general lowland surface beyond. This former lowland surface, now raised to about 1,000 feet above sea level, makes the even upland country well shown about Cincinnati. This level upland extends east beyond the Scioto and north toward the central part of the State. It seems probable that the level surface about Delaware is the northern extension of this plain.

Following the uplift which brought this plain to its present position well above sea level, the streams began at once to cut into it and to roughen its surface. In consequence, considerable parts of the State near the main drainage lines are now hilly. Back from these main

[1]Barrell, J., Rhythms and the measurements of geologic time. Bull. G. S. A., Vol. 28, pp. 884–5. 1917.

river valleys the plain is less cut, sometimes hardly stream cut at all. The even surface of Delaware County may be attributed to its position away from main drainage lines.

Structural Features and Composition

There is brought together in the following pages a number of structural features and compositions of the bed-rocks, not considered when the formations were taken up in order.

LIMESTONES

The chemical composition of the limestones is shown in the following table:

TABLE OF LIMESTONE ANALYSES

	1 Columbus (Bellepoint)	2 Columbus (Heavy beds above coral layer)	3 Columbus (Klondike)	4 Columbus (Klondike)	5 Columbus (Klondike)	6 Columbus (Klondike)	7 Delaware (Below chert)	8 Delaware (Below chert)	9 Delaware (Upper)
Silica, SiO_2	1.99	2.48	1.63	1.30	2.1	3.06	6.76	10.36	3.02
Alumina, Al_2O_3	.30	.31	.39	.28	.5	.26	.58	2.71	.95
Ferric oxide, Fe_2O_3	.27	.45	.19	....	....	....	.77	.05	.25
Phosphorus pentoxide, P_2O_5	tr.	tr.	.01	....	....	....	.42	....	....
Titanic oxide, TiO_2	.02	.03	.01	....	....	....	.07	....	....
Lime, CaO	33.41	39.82	48.30	....	....	50.46	39.34	....	....
Magnesia, MgO	17.84	12.50	5.61	....	....	3.09	10.20	....	....
Manganous oxide, MnO	.02	.02	.02	....	....	....	.06	....	....
Carbon dioxide, CO_2	45.48	44.41	44.08	....	....	*	41.41	....	....
Carbon, C(organic)	.07	.01	.09	....	....	....	.03	....	....
Sulphur, S	.116	.162	.08	....	....	....	.353	....	....
Loss at 105°C., H_2O	.21	.03	.03	....	....	*	.09	....	....
Calcium carbonate, $CaCO_3$	(59.66)	(72.19)	(87.32)	92.64	94.6	(90.26)	(71.32)	69.80	91.31
Magnesium carbonate, $MgCO_3$	(37.56)	(26.25)	(11.78)	4.75	2.8	(6.49)	(21.44)	17.21	5.12
Total	99.726	100.222	100.44	98.97	100.	100.11	100.083	100.13	100.65

*Ignition.

MINERAL COMPOSITION (Calculated to 100%)

	1	2	3	4	5	6	7	8	9
Calcite, $CaCO_3$	15.06	40.28	72.56	88.12	91.39	82.78	45.62	49.88	85.24
Dolomite, (CaMg) CO_3	82.07	56.57	25.54	10.43	6.21	14.04	46.78	38.11	11.21
Kaolin, $Al_2O_3.2SiO_2.2H_2O$	.76	.77	.97	.35	.64	.33	1.44	7.36	2.38
Quartz, SiO_2	1.64	1.79	.78	1.00	1.58	2.75	5.50	4.61	.99
Pyrite, FeS_2	.23	.59	.15	.10	.18	.10	.66	.04	.18
Limonite $2Fe_2O_3.3H_2O$	.24	....	....	....	....	....	....	....	....

1 Columbus limestone. Bellepoint member below coral layer. Sampled through 20 feet. White Sulphur quarry. Analyst D. J. Demorest.

2 Columbus limestone. Sp. macrothyris zone. Sampled 4½ feet above the coral layer. White Sulphur quarry. Analyst D. J. Demorest.

3 Columbus limestone. Sampled working face of Klondike quarry. Analyst D. J. Demorest.

4 Columbus limestone. Klondike quarry. Analyst unknown. From Geol. Survey of Ohio, Bull. 4, p. 61.

5 Columbus limestone. Klondike quarry. Analyst unknown. Analysis furnished by The Scioto Lime and Stone Co.

6 Columbus limestone. Sampled boring from Klondike member, 1 mile NNE. of Radnor. Furnished by J. T. Herrick, Analyst Charles P. Hoover.

7 Delaware limestone. Delaware quarries, sampled below the 1½ foot chert layer. Analyst D. J. Demorest.

8 Delaware limestone. Same as No. 7. Analyst unknown. Geol. Survey of Ohio, Bull. 4, p. 61.

9 Delaware limestone. Delaware quarries. Sampled 5½ feet of shelly beds above 1½-foot chert. Analyst unknown. Geol. Survey of Ohio, Bull. 4, p. 61.

From the chemical composition the mineral composition has been calculated,[1] which gives varying proportions of calcite, dolomite, quartz, kaolin, and pyrite. These can be seen in the thin sections, except the kaolin, which is in too fine particles.

The Columbus limestone above the coral layer may be taken as a typical limestone. In the hand specimen it is a light brownish-gray, fine-grained rock, with several large and a number of smaller fossil fragments. Numerous small, white, shining grains of calcite are seen replacing crinoid discs. The main mass of the rock is an aggregate of minute grains of carbonate.

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[1]The microscope shows the following minerals present in the rock: calcite, dolomite, quartz, pyrite. The alumina of the analysis is assumed to occur in kaolin. In calculating the mineral composition, the sulphur has been combined with the iron, which in the analysis is stated as Fe_2O_3, to give pyrite. To the alumina there has been assigned silica and water in the proper proportions to give kaolin (clay). The remainder of the silica is given as quartz. The CO_2 has been assigned to the CaO and MgO to give the carbonates, and enough calcium carbonate assigned to the magnesium carbonate to give the dolomite. The remainder of the calcium carbonate is given as calcite.

In making these assignments the amounts given in the analyses are assigned according to the molecular proportions of the substances used. For example, in analysis 1 in the table, enough CO_2 is assigned to the 33.41 parts of CaO in the proportion of 44:56 (their respective molecular proportions), giving 59.66 parts of $CaCO_3$. In the same way CO_2 is assigned to the 17.84 parts of MgO in the proportion of 44:40, giving 37.46 parts of $MgCO_3$. All of the $MgCO_3$ is in dolomite, each molecule of $MgCO_3$ requiring in dolomite another of $CaCO_3$. $CaCO_3$ is therefore assigned to the 37.46 parts of $MgCO_3$ in the proportion of 100:84, giving 82.06 parts of dolomite, and leaving 15.06 $CaCO_3$ as calcite. In similar manner the .30 parts of Al_2O_3 takes SiO_2 from the 1.99 parts of SiO_2, making .76 parts of kaolin, and leaving 1.64 parts of the silica for quartz.

The thin section (see Plate IV A) shows:

1 Calcite.
   A. Replacing the fossil fragments. Often single calcite grains replace crinoid discs which are over 1 mm. in diameter.
   B. As a matrix of irregular grains between the fossil fragments. These grains vary in size up to .1 mm., though usually they are much smaller.
2 Dolomite. In small rhombic crystals to a maximum of .15 mm. They lie scattered through the matrix between the fossil fragments, though sometimes they are enclosed in the calcite filling of the fossils. They make up approximately one-third of the section. Usually they are clear, though occasionally they have minute opaque inclusions crowded near the center.
3 Quartz. Scattered grains to .2 mm., angular to subangular in outline, rarely oval. A little quartz in the form of chalcedony is present.
4 Pyrite. A little in scattered grains, often collected within the fossil fragments.
5 Limonite. A very little.

The origin of the different minerals is probably as follows: The fossil fragments were originally calcium carbonate. Whether originally calcite or aragonite (the orthorhombic form of calcium carbonate), the original carbonate has recrystallized to the present calcite.

The granular calcite matrix shows no evidence of direct organic origin. It may be of mechanical origin; the fine silt made by the mechanical grinding of shells, etc., by the waves, settling later from suspension in the sea water. Or it may be a chemical precipitate, either with or without the agency of bacteria. Vaughan[1] has described the formation of fine carbonate (calcite) muds in the shallow waters back of the Florida keys, through the action of lime-precipitating bacteria. Possibly that is the process by which the matrix of our Devonian limestones was formed. If so, since the granular carbonate matrix makes up the larger part, in some layers almost the whole, of our limestones, this process of chemical precipitation by bacteria (biochemical precipitation) was the most important agency in their accumulation.

The dolomite is of later growth than the calcite. At scattered points in the lime mud, dolomite ($[CaMg]CO_3$) formed from the calcite ($CaCO_3$) by exchange for half of the original calcium atoms of the calcite, atoms of magnesium taken from magnesium salts in the sea water. The growing dolomite grains took their own crystal form. No reason is given for the fact that throughout our Devonian limestones these crystals grew to a nearly uniform maximum size of .1 to .15 mm. and then stopped.

The quartz grains are all small, up to .1 mm., rarely .2 mm., usually angular, and are not very abundant, though they are consistently present. They are of sufficiently small size to have been blown out to sea by wind. It is less probable that they may have been floated out

[1]Vaughan, T. Wayland, A contribution to the geologic history of the Floridian plateau. Carnegie Institute of Washington. Publication 133, pp. 129–137. 1910.

by water currents. The small amount of chalcedonic quartz is deposited from ground water.

The pyrite was probably formed at the time of the formation of the rock, or soon after, directly or indirectly through the influence of organic matter in the rock, reducing iron salts in the ground water.

The other Devonian limestones differ from the sample described mainly in the proportion of the separate constituents present. Specimens of the Delaware limestone show very few fossils and are almost wholly the material making the matrix in the Columbus; they have a larger proportion of dolomite crystals, more pyrite, and more abundant sand grains. They have also many small, yellow, horny fossil fragments. All the limestones have the small sand grains. In a section from the basal conglomerate layer of the Columbus, the sand grains are much more numerous than at any of the higher levels, larger, reaching .25 mm., and often well rounded. Here they are doubtless water carried, in the shallow waters of beginning mid-Devonian time.

DOLOMITES

All of the limestones of the county are, at least to a slight degree, dolomitic. This is shown by the presence of varying amounts of $MgCO_3$ in the analyses and by the occurrence of the small dolomite rhombs in all thin sections. Two of the limestones have such a large percentage of dolomite that they should be called dolomites and not limestone. These are the Bellepoint member of the Columbus and the Monroe.

The Bellepoint limestone is a massive, brown, slightly streaked, fine-grained rock. In thin section the rock is an aggregate of dolomite grains. This occurs in part as numerous larger dolomite rhombs to .15 mm.; more abundantly as smaller grains, usually rhombs, to .05 mm.; and as irregular carbonate areas between the two former. In places single areas up to several millimeters across consist of a single grain of dolomite in which lie scattered dolomite crystals. Calcite grains are doubtless present but are not recognizable without staining. The finer opaque constituents are often crowded at the centers of the larger dolomite crystals. Small grains of pyrite and grains and films of limonite are present. The hand specimens show grains and streaks of carbonaceous matter (the rock has an oily smell when freshly broken), and the fine dark material in the slide is in part probably this same organic material. A few minute quartz grains to .02 mm. are present.

The chemical analysis and calculated mineral composition of the Bellepoint rock are given in column 1 of the table (p. 46), where it is seen that the dolomite is between five and six times as abundant as the calcite.

The Monroe dolomite in its upper part is markedly different from the overlying Bellepoint dolomite. The rock is dense, almost as fine-grained as a lithographic stone. The microscope shows an aggregate of minute polygonal grains of dolomite, from .02 to .01 mm. in size, the grains showing few or no crystal outlines. Small scattered grains of quartz occur, to .02 to .1 mm.

Dolomites[1] are secondary rocks, originating through the substitution of magnesium for one-half of the original calcium in the rock. This replacement may have taken place while the sediments were beneath the sea, either at the time of accumulation or after burial and while still saturated with ocean water; or after emergence and through the agency of circulating underground waters. The scattered dolomite crystals found through all of the limestones (partial dolomitization) and the complete or almost complete dolomitization of certain beds, chiefly the Bellepoint dolomite, are the same process carried to different lengths. The uniform distribution of the grains through the rock and the uniformity of distribution of the dolomitic bands across the county, together with the complete lack of dependence of the dolomitization on joints or planes which might have controlled the flow of the ground water, show that circulating underground water was not the cause. The dolomitization took place through an agency acting in the same general way and on the same scale, as that through which the beds were accumulated; it took place while the sediments were on the sea bottom. Whether it was practically contemporaneous with their accumulation, or later, after burial but before uplift, it is impossible to say. Neither is it possible to state what change in the character of the ocean water or other controlling conditions was responsible for the greater dolomitization of some layers compared with others, in particular for the nearly complete dolomitization of the Bellepoint member; nor for the marked difference in the Bellepoint member of the Columbus and the Monroe.

CONCRETIONS

Concretions are masses, usually more or less rounded, formed within the rock subsequent to its deposition, by material deposited from solution in the ground water. Concretions are common and sometimes striking features in the sedimentary rocks of Delaware County. The following types will be described:

1. Chert concretions in the Columbus and Delaware limestones.
2. Limestone concretions in the Olentangy shale.
3. Limestone concretions in the Ohio shale.
4. Iron sulphide concretions in the Ohio shale.

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[1]Two excellent papers on dolomite are:
Steidtmann, E., Origin of Dolomite as Disclosed by Stains and Other Methods. Bull. G. S. A., Vol. 28, pp. 431–50, 1917.
Van Tuyl, Francis M., The Origin of Dolomite. Iowa Geological Survey, Vol. 25, pp. 251–422, 1916.

Chert (flint) concretions

Chert concretions are present in both the Columbus and Delaware limestones, more abundantly in the latter. In the Columbus they occur mainly as isolated lenticular masses, often to a foot or more in length, usually in the bedding planes. In the southern part of the county there is an extensive development of chert through a vertical thickness of about eight feet, at a horizon just above the coral layer. This band,

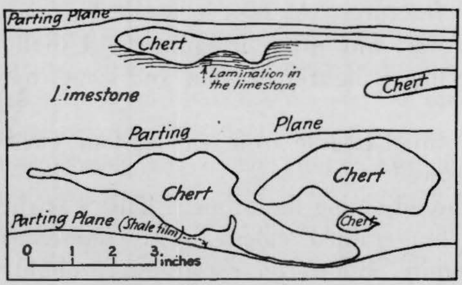


Fig. 10

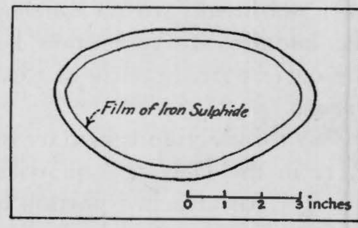


Fig. 11

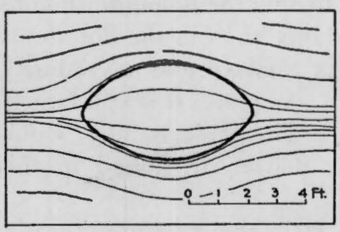


Fig 12

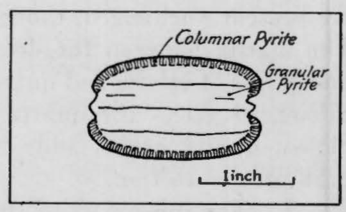


Fig. 13

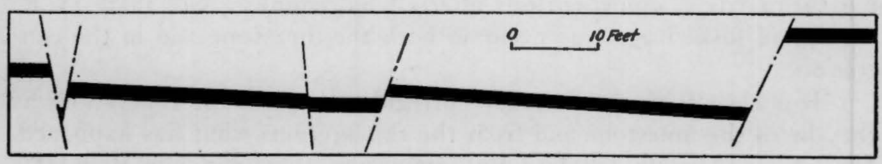


Fig. 14

Fig. 10. Chert nodules, Delaware quarries.
Fig. 11. Limestone concretion in Olentangy shale.
Fig. 12. Limestone concretion in Ohio shale.
Fig. 13. Pyrite concretion in Ohio shale.
Fig. 14. Faulting in quarry at Delaware; west end of section to the right.

the Eversole chert, or Zone D of Stauffer, is well shown at the O'Shaughnessy dam and in Eversole Run, but disappears north before reaching Bellepoint. This layer contains large masses of chert which enclose numbers of well preserved fossils. It is from this layer that the larger part of the gastropods reported from the Columbus are obtained.

Chert bands are common in the middle and upper part of the Delaware. They sometimes are found as scattered flattened nodules from a few inches to more than a foot in length, in the rock or in the bedding planes. In the upper part of the Delaware they make a large part of single beds of considerable thickness. One such layer, a foot and a half in thickness, is found in the upper part of the Delaware quarries, and a layer 5 feet thick near the top of the Delaware in the Deep Run section at Orange road.

The chert varies from light to dark gray, is dense and porcelain-like, and breaks with a conchoidal fracture. As seen in vertical section the nodules are sometimes lenticular, but often irregular. Usually the outer part, because of weathering, is lighter in color and somewhat porous.

A thin section taken across a small nodule from the 1½-foot chert layer in the Delaware quarries showed:

1. An attached portion of the adjoining limestone. This was the typical limestone; largely very fine-grained calcite, with numerous scattered rhombic crystals of dolomite, minute quartz grains (probably of wind origin), and darker, dust-like, indeterminable material.

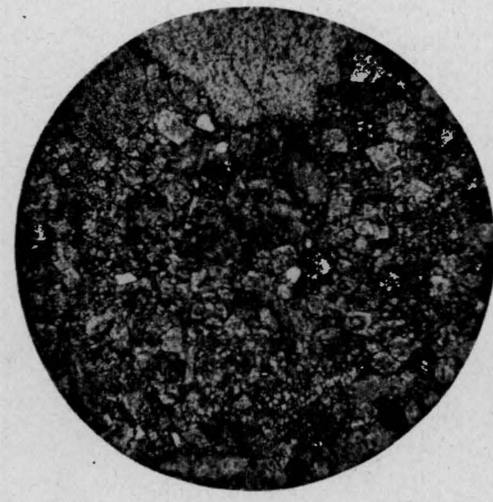
2. The outer part of the concretion. In this the dolomite rhombs are present unchanged, though in less abundance than in the limestone. The matrix between the dolomite crystals is a mixture of exceedingly fine grains of calcite and quartz (chalcedony). In places it is still largely calcite, in places the quartz predominates. The same minute, wind-blown, quartz grains and opaque granular matter are found in this part of the section.

3. The inner part of the concretion. Here the dolomite crystals, the small wind-blown sand grains, and opaque impurities are found, but the matrix is almost entirely quartz (chalcedony). See Plate IV B.

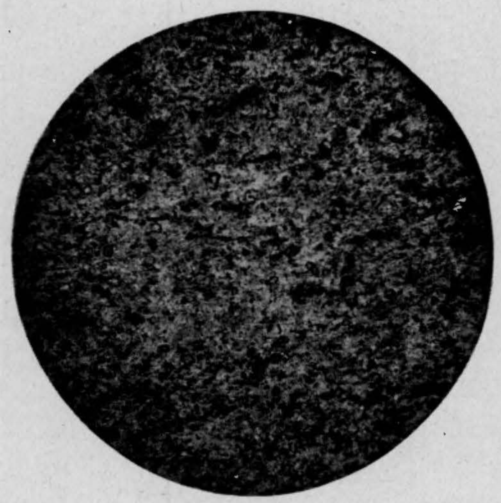
Small fossil fragments occur in both the limestone and in the concretion.

It is clear from the frequently irregular shape of the concretions as they lie in the limestone and from the thin sections what has happened. Fine-grained quartz (chalcedony), in grains averaging less than .005 mm., has more or less completely replaced the original materials of the limestone. That replacement started at the center and worked out into the adjacent rock. The wind-blown quartz grains of the original rock remain as they were. The dolomite crystals retain both their form and substance. They are less numerous in the chert than in the adjacent limestone; perhaps that was an original difference, or possibly some of the dolomite crystals have been replaced. The granular calcite matrix, however, has been replaced in varying proportions, to an increasing degree in the older central part of the concretion.

The limestone was in essentially its present condition, partly dolomitized, when the chert was formed. The deposition of the silica



A.—Micro-section of Columbus limestone. × 30. The four light grains are quartz, the somewhat larger rhombic grains dolomite, the remainder calcite.



B.—Micro-section of chert. × 30. Mainly fine-grained quartz.

was selective, replacing the calcite but not the dolomite. Figure 10 shows that the concretion grew mainly by substitution of quartz for the original limestone, but that there was some pushing aside of the adjacent layers of the limestone.

Sections of other cherts show the same structures and point to the same mode of origin as the one just described. Tarr[1] has described the cherts of the Burlington limestone and considers them to have accumulated as silica gels on the sea bottom. That explanation does not seem to apply here. It is more than likely that different cherts have somewhat different origins and Tarr's paper serves as an excellent introduction to their study.

Limestone concretions in the Olentangy shale

Limestone concretions are found at a number of levels in the Olentangy shale. In their simplest form these are circular in horizontal plane, nearly elliptical in vertical section (Fig. 11), though more pointed below than above, varying from six to twelve inches in horizontal diameter. They are of the same blue-gray color as the enclosing shale, are fine-grained and dense, and can hardly be broken with a sledge, though when thrown aside and allowed to weather, they soon break down into a heap of small angular fragments. When broken across they show a line of marcasite (FeS_2) extending completely around the concretion about a half inch from the outside. Isolated concretions of the type described occur at certain levels near the top of the shale. In these levels some concretions are larger and more irregular, reaching 2 feet in diameter. Toward the bottom of the formation the same type of rock occurs in lenticular masses, sometimes united to continuous beds, reaching 10 inches in thickness. A sample collected from one of these lower layers, four feet above stream level at the north end of the shale bank south of Delaware, was analyzed by Prof. D. J. Demorest for the Geological Survey of Ohio, and his results follow:

Silica, SiO_2	12.58
Alumina, Al_2O_3	3.25
Ferric oxide, Fe_2O_3	1.58
Phosphorus pentoxide, P_2O_5	tr.
Titanic oxide, TiO_2	.11
Lime, CaO	43.50
Magnesia, MgO	1.58
Manganous oxide, MnO	.11
Carbon dioxide, CO_2	36.06
Carbon, C(organic)	.26
Sulphur, S	.305
Moisture at 105°C	.16
Total	99.495

[1]Tarr, W. A., Origin of the Chert in the Burlington Limestone, Am. Jour. Sci., Vol. 44, pp. 409–452, 1917.

This analysis recalculated for the mineral composition, and to a 100 per cent total, with TiO_2 and MnO omitted, gives the following:

Calcite, $CaCO_3$	74.81
Dolomite, (CaMg) CO_3	7.38
Quartz, SiO_2	8.89
Kaolin, $Al_2O_3.2SiO_2.2H_2O$	8.35
Pyrite, FeS_2	.57
Total	100.

In thin sections the rock is seen to be made up of an aggregate of very small grains of carbonate, in one slide averaging .1 mm., in another mostly finer, averaging .02 mm., though in parts of the section reaching .1 mm. Calcite and dolomite are not separable in the section though the analysis shows the former is ten times the more abundant. Scattered small grains of iron sulphide occur, many of them small cubes (pyrite), to .04 mm. A very little chalcedonic quartz shows. The sections are taken from different pieces from those used for the analysis, hence the variation from the calculated amount of pyrite and quartz.

Limestone concretions in the Ohio shale

Large rounded concretions of dark-brown limestone are very abundant in all the exposures of the lower part of the Ohio shale along the Olentangy and the small streams entering it from the east (Plate III B). They vary from a few inches to six or eight feet in diameter, the smaller ones being as round as a cannon ball, while the larger ones are flattened and elliptical in vertical cross section. The bedding of the shale is bent about them above and below, and when one is broken vertically so that the internal structure shows (Fig. 12), the lamination of the shale can be seen to pass through the concretion from side to side, bent in the same fashion but in less degree as the shale outside, above and below the concretion. It is clear that the concretion was formed by the deposit of material between some of the layers of the shale, pushing them apart, and at the same time displacing the layers of shale above and below. During the earlier stages, represented by the smaller concretions, the growth vertically and horizontally was nearly equal and the concretion spherical. Later the growth was greater horizontally than vertically, possibly on account of the increasing difficulty in displacing the beds against the pressure of the overlying load of sediment. That this overload was considerable is indicated by the symmetry of the shale distortion when considered in relation to a horizontal plane through the center of the concretion, showing that it met equal resistance in displacing the beds below and above.

The smaller concretions are solid to the center, but in the larger ones the center is more or less broken and healed with coarsely crystallized calcite. Sometimes barite is found here. At the centers of some of the concretions fragments of fish skeletons have been found, which served as the nucleus about which the concretion grew. It was from this source that Herzer got much of the material which Newberry used in working out the Ohio Devonian fish fauna.

The concretions are found only in the lower part of the Ohio shale. They are absent from the middle beds on Alum Creek and the upper beds on Big Walnut Creek. They are found entirely across the State of Ohio from the Ohio River to Lake Erie, and even beyond the State boundaries. A well-known locality outside the State is at Kettle Point, Ontario, where they have been described by Daly.[1] They appear to be related in some unknown way to a water circulation through the Ohio shale just above the impervious Olentangy shale; under conditions, of course, entirely different from today, when the concretions are at the surface, in the zone of weathering and subject to disintegration.

The following analysis of the rock was made for the Geological Survey of Ohio by Prof. D. J. Demorest:

Silica, SiO_2	9.08
Alumina, Al_2O_3	1.87
Ferric oxide, Fe_2O_3	5.03
Phosphorus pentoxide, P_2O_5	tr.
Titanic oxide, TiO_2	.12
Lime, CaO	27.29
Magnesia, MgO	13.80
Manganous oxide, MnO	.50
Carbon dioxide, CO_2	38.83
Carbon, C(organic)	2.25
Sulphur, S	.675
Moisture at 105°	.20
Total	99.645

The mineral composition of the rock has been calculated from the chemical analysis and is given below. In this calculation the organic carbon, TiO_2, and MnO have been ignored, and the total calculated to 100 per cent.

Dolomite, $(CaMg)CO_3$	65.26
Calcite, $CaCO_3$	15.07
Siderite, $FeCO_3$	4.98
Kaolin, $Al_2O_3.2SiO_2.2H_2O$	4.82
Quartz, SiO_2	6.91
Pyrite, FeS_2	1.31
Limonite, $2Fe_2O_3.3H_2O$	1.65
	100.

[1]Daly, R. A. The calcareous concretions of Kettle Point, Lambton County, Ontario, Journal of Geology, Vol. 8, pp. 135–150, 1900.

In thin sections under the microscope the rock is seen to be made up of an aggregate of calcite and dolomite (not separable), with an average size of .1 millimeter, a few very fine grains of quartz, some pyrite and limonite. A few small patches and bands of chalcedony occur. Because of the large amount of insoluble impurities present, more than 17 per cent., the rock weathers on solution to a brownish porous ochre.

The origin of the concretions through deposition of dolomite and calcite, often about fossil nuclei, is clear. It is not known why such deposition took place, what finally limited the growth of the concretion, nor why these concretions are found only in the lower part of the Ohio shale. Evidently more is not known than is known about them, and the same is true of the other kinds of concretions found in the local rocks.

Iron sulphide concretions

Iron sulphide, either in isometric (pyrite) or orthorhombic (marcasite) form, is present in all local rocks. It occurs in small amount as scattered grains or small granular aggregates in the limestones, but is abundant in the shales. The two minerals are not easy to tell apart. Both are brassy yellow (pyrite is commonly called "fool's gold"), but the marcasite is paler than the pyrite. The pyrite crystals are cubes, pyritohedrons, or octahedrons, or combinations of these. The marcasite weathers more easily than the pyrite; pieces, left standing in the laboratory, take oxygen and water from the air, and become coated with white silky, fibrous melanterite or copperas ($FeSO_4 \cdot 7H_2O$).

In the Ohio shale the iron sulphide occurs in scattered grains and crystals, or in narrow bands and lenses in the bedding planes. Frequently it forms mushroom-like concretions, two to four inches in diameter and an inch or more high. These are formed later than the time of the accumulation of the shale, as is shown by the fact that the lamination planes of the shale run through them. Some of the concretions are mainly pyrite, some marcasite, while others appear to be made of alternating shells of the two.

In the Olentangy shale iron sulphide concretions are found, often taking the form of clusters of twinned crystals of marcasite. Both pyrite and marcasite easily weather, and are responsible by their weathering for a number of features: for the cream or yellow discoloration of some of the limestones for a certain distance in from the joint surfaces, for the rusty stains over the surface of the shale, for the iron springs, and for the yellow color of the till. They are responsible, too, for the copperas frequently found on the surface of the shale cliffs, left behind on the evaporation of the ground water which has soaked through to the face of the cliff.

Structural Features of the Bed-rock

Dip and folding.—The rock formations through central Ohio have an average dip to the south of east of about 25 feet per mile. This, expressed in degrees, is about one-fourth of one degree, an angle quite inappreciable to the eye; so that in the field the beds generally appear horizontal. This value of 25 feet to the mile is an average; actually the eastward dipping surface of the formation is warped. The top of the Columbus limestone at the Olentangy River in Delaware, for example, is about 800 feet above sea level, i. e. about 45 feet below the bed of the river; a mile west at Campbell's quarry, it is 50 feet higher. A little west, across the Hocking Valley Railroad, the rocks dip west. Five miles west, at Warrensburg, the calculated position of the top of the Columbus is 970 feet above the sea, an average rise of 28 feet per mile between the two rivers. There are variations, as well, north and south. Two low anticlines are shown by the two outcrops of the Columbus limestone in the Olentangy Valley in Liberty Township. In the northern belt, northeast of Hyattsville, the top of the Columbus rises from river level to forty feet above in the west bank of the river, and then drops to river level. Two miles south, southwest of Lewis Center, the Columbus reappears in the bed of the river, rises again to nearly 40 feet above stream level, and then drops to stream level, and disappears just north of the Powell road. The surface of the formation is thus seen to be not a plane but a warped surface. This curving of the rock beds can sometimes be seen on a smaller scale but more sharply in gentle local folds. One such, south of Stratford, is shown in Plate VA.

The position of the rocks at the time of their formation was doubtless not perfectly horizontal. No sea bottom is perfectly flat. But the general easterly dip of the formations in Ohio is not due to deposition on an uneven sea bottom, but to a combination of two outside causes; the sinking of the basin or geosyncline, in which the Paleozoic rocks of the Appalachian area were being deposited, and to the movements which accompanied the folding at the end of Paleozoic time. That folding was most severe in central Pennsylvania, but was felt as far west as central Ohio.

Joints.—Rock formations are cut in various directions by joints, planes along which the rock has broken. They may be due to a variety of causes, but in sedimentary rocks the vast majority are the result of bending and twisting of the beds after partial or complete solidification. The most abundant joints are those which follow the bedding planes. The text-books on geology generally, by implication at least, limit the term to the cracks which make an angle with the bedding planes, in horizontal sediments usually a large angle. But the open cracks which lie in the bedding planes have a like origin with the others. One can illustrate this by bending a pack of playing cards; it cannot be done without the cards slipping by each other on their faces. In similar fashion the bedding planes in a series of sedimentary rocks are planes of weakness. They are not at the start open, but when the rocks are bent the layers move on each other, as do the playing cards, and may be opened and form joints.

In addition to the bedding-plane joints there are numerous joints, usually nearly vertical, which cut across the bedding planes. These joints occur commonly in two or more sets which make large angles with each other. Sometimes, particularly in the Ohio shales, there are more than two sets and the whole fracturing becomes complex.

The joints divide all the rock formations into blocks. In some places the rock on the two sides of a joint is so close together that it seems unbroken. It may even be impossible to see the crack itself, its presence being recognized by noting the slight stain of the rock along it due to the action of the minute film of water which has penetrated it. Usually the joint is open, commonly to but a small fraction of an inch.

Quarrying

That the rock formations exist thus as actual or potential blocks is of the utmost importance, both for artificial and natural processes. It makes quarrying of the rock easy. The rocks split readily along the bedding joints, and the vertical joints are taken advantage of in setting the blasts. Certain natural processes are favored by the joints.

Weathering

Rock disintegration by weathering is favored. The effectiveness of changes of temperature, frost action, and chemical solution is multiplied many times by joints.

Ground water flow

The only porous bed-rocks in the county are the Berea sandstone and the sandy beds of the Cuyahoga formation. In all the other bed-rock formations the flow of water is through joints, and this takes place fairly readily in all except the Olentangy shale, which is so soft that the joints are closed by weight of the overlying rocks and the rock is thus rendered impermeable.

In the more soluble limestones, the surface water flowing down along the cracks has dissolved the limestone wall on either side, and widened the cracks to open fissures. With this widening of the cracks passage of water becomes easier. This process is best shown along the

Scioto River in the upper part (Klondike member) of the Columbus limestone. In many places the enlarged cracks make holes (sinks) at the surface. A succession of such sinks can be traced along the east boundary of the Columbus limestone north from the Delaware-Marysville road for two miles, and along the east side of the Delaware limestone outlier north from Rathbone. These sinks are sometimes funnel-shaped openings to an underground escape, the rock showing only at the bottom of the funnel, which may be five to fifteen feet in depth. Elsewhere dry weather streams, up to as much as a quarter of a mile in length, disappear through them. The sinks would be more numerous were it not for the mantling of the limestone belt by the glacial drift. Some of the sinks have been reopened in post-glacial time, but probably many more were permanently buried.

In its further underground course the water may widen the cracks to caves. If the widened crack was vertical the cave is narrow and high; if it was a bedding-plane crack, the cave is wide and low. In the lower levels near the river the water may emerge with strong flow as a spring.

Stream channel deepening

Rock jointing favors deepening the beds of the streams, for, contrary to the statements of the text-books, streams, in central Ohio at least, do not deepen their channel beds in the rock by the wear of so-called tools, sand and gravel, which they roll down stream. This mechanical wear by tools is abrasion. The proof that the rock beds of the streams have not been deepened by abrasion is in the unworn, angular, blocky character of the channel bed wherever it is shown, and this is true of stream beds in all of the formations, even in the soft Olentangy shale. Anyone inspecting such a rock bed can see that it has been brought to its present condition by the removal of joint blocks, and in some cases the dislodged blocks can be seen only a little way down-valley from their original position. This process of natural quarrying in the stream bed is called *plucking*, and the indispensable prerequisite to plucking is that the rock be jointed. The gravel rolled along by the stream may have worn the bed of the stream a little. It certainly may itself be worn, as its rounded form often shows. But whatever it did in the way of wearing the channel bed was work thrown away; for before the limestone blocks in the stream bed on which it was working could be worn away to any degree by this process they were quarried loose by weathering processes (frost, changes of temperature, solution along joint cracks), and, if not too large, were swept on down stream. That the channel bed is not being lowered by the mechanical wear of stream-swept debris (by abrasion), is shown by the almost complete absence of the characteristic rounded surface so well shown by the rounded and worn debris itself. Plate II B shows the blocky character of the stream bed where the Olentangy is flowing on Ohio shale.

Faults.—In the bending and cracking of the rocks the beds sometimes slipped by each other and faults were produced. The only illustration of this, but an excellent one, is in the quarries northeast of the Hocking Valley station at Delaware. The beds here form a low arch or anticline, the axis of which runs roughly north-south, a little east of the railroad. Along the crest the beds are nearly horizontal; on the east side of the quarry they dip gently to the east; while on the west side they dip to the west, and this westward dip is continued through the quarries west of the track. The bending which produced the fold in the probably rigid rock broke the limestone. The fault can be recognized in the southwest corner of the quarry east of the track by the failure of the prominent 18-inch chert seam near the top of the west wall to show at the same level on the south wall. It has dropped 8½ feet. The fault plane dips 65° east, the hanging wall block, the east block, has gone down and it is therefore a normal fault. The fault can be traced north across the floor of the quarry, with a slight curve and an average direction N. 20° E. The displacement when the fault cuts the north wall of the quarry is four feet. At a point near its south end the fault face shows, and the striations made by the movement make an angle of 20° with the vertical, down to the north. At the north side of the quarry the striations, as earlier shown on a face since removed, were vertically down the fault face. Other smaller faults of small displacement occur, parallel to the main fault. Figure 14 shows a series of five normal faults, including the main 8½ foot fault, as they formerly stood on the south wall of the quarry.

This fault is ideal in showing the typical fault characteristics: connection of folding and jointing, amount of varying vertical displacement, curving course, dip of fault plane, direction of movement along fault face, and sealing of the narrow fissure by carbonate of lime, deposited by rising waters before the rocks came up to the zone of weathering.

The average direction of five of the nearly parallel main joints, roughly paralleling the axis of the fold, at the southwest corner of the quarry, is N. 29° E. the cross joints are less consistent, N. 27° W. to N. 73° W., and usually end against the northeast series. They correspond to the *face slip*, (throughgoing joints), and *butt slip*, (cross joints), sometimes applied to jointing in coal.[1] The former relieve the main stresses due to the folding, the latter the minor stresses within the primary joint blocks. All of the faults have arisen through the movement of the blocks along the main N. 29° E. joints.

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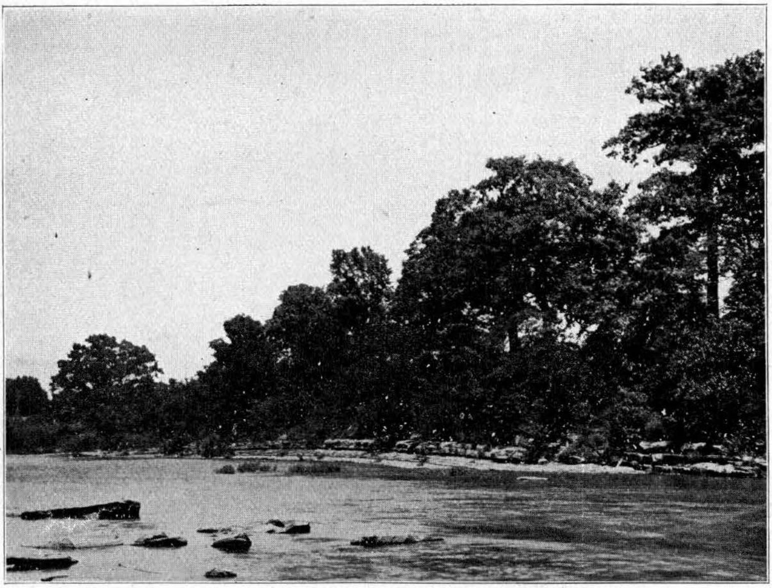
[1]Ashley, G. H., Coal Deposits of Indiana, Twenty-third Annual Report, Indiana Dept. Geol. & Natl. Resources, p. 27, 1899.



A.—Small anticline in Delaware limestone on the Olentangy River south of Stratford.

B.—Fault in Delaware limestone, Delaware. This shows the line of the fault, also the throw and the heave, by the displacement of the flint layer.

Bedding planes.—Bedding planes in sedimentary rocks mean cessation or change in character of sedimentation. This may have been due to shifting ocean currents, to storms, or to other causes. In the shallow waters in which sandstones were accumulating there was at times removal of sediment from place to place on the sea bottom. The Columbus and Delaware limestones are contrasted in that the Delaware has frequently shale in the partings (Fig. 7), while the Columbus either does not show them at all or not to anything like the same degree. The exact cause of bedding planes, including their absence in certain massive beds, and closeness in others, and of the presence of shale partings, is not clear. Professor Shaler of Harvard explained the shaly partings in limestones as due to earthquakes, which threw the mud into the water, killing the organisms and forming a fossiliferous shale layer between the beds. The explanation may be fanciful; if it is, it only points to the difficulty of the problem.

Cross-bedding.—This is found in the sandstones; and any section of the Berea shows a gentle cross-bedding structure. It has not been noted in the limestones, which often preserve an almost complete uniformity of bedding through a large quarry, though when followed farther the limestones too show changes in thickness and in the character of the individual beds.

Ripple marks.—Ripple marks, due to bottom currents, are common, and in many places beautifully shown in the Berea sandstone. They were seen at one locality in the Columbus limestone. A mile and a quarter south of Bellepoint, on the east side of the river, a small ravine crosses an east-west road about one-third of a mile east of the river. A small quarry is opened in the ravine on the south side of the road. Here, five feet below the Columbus-Delaware contact, an excellent ripple-marked surface is shown. Twenty-four ridges were counted in a distance of thirty-five feet, an average length from crest to crest of almost eighteen inches. The direction of the ridges was N. 20° W., and the current which made them apparently was from the northeast. The Columbus sea at that time was not too deep to be affected by bottom currents.

Stylolites—Stylolites (hackle-tooth) is "a series of alternating, interpenetrating columns of stone which form an irregular, interlocked parting or suture" most commonly "along the bedding or lamination planes of the limestone, resulting in an intricate interteething of the rock by the alternating downward and upward projection of the columns of one layer of rock into the opposite."[1] They are abundant along the bedding planes of the Columbus limestone, but are less common in the

[1]Stockdale, P. B., Stylolites: their nature and origin. Indiana University Studies, Vol. 9. Study 55. Dec. 1922, p. 7. This paper is an excellent account of the whole subject.

more shaly and less soluble Delaware. Figure 15 is a tracing of a profile of a seam taken from a drill core cutting the Columbus limestone. They are shown by Stockdale[1] to originate in hardened limestone by uneven solution of limestone along the joint plane, leaving the insoluble residue as a dark shaly deposit along the contact of the two rocks, especially as cappings to the projecting points. The vertical sides are often grooved where the two masses have been forced by each other. They run continuously for considerable distances, and may be of help in identification of beds in different parts of a single quarry.

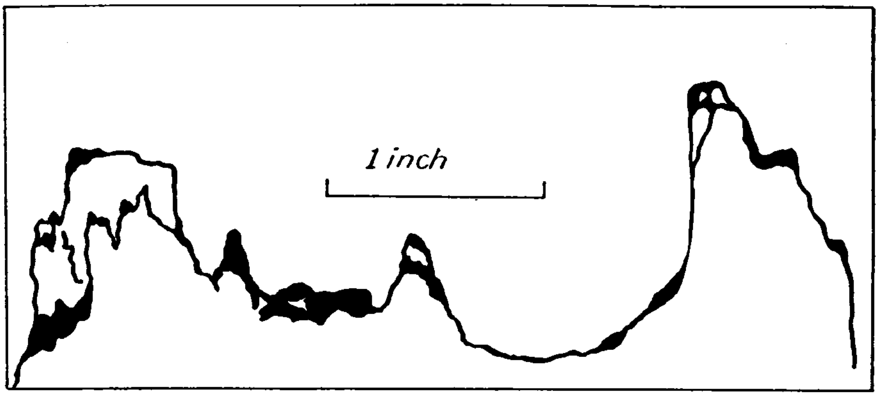


Fig. 15. Stylolite (hackle-tooth) on bedding plane, Columbus limestone.

Cone-in-cone structure.—Certain layers of limestone, up to three inches thick, in the middle part of the Ohio shale, show cone-in-cone structure. These layers can be seen at Alum Creek, on the Delaware-Sunbury highway. The structure[2] consists of a series of cones within cones. Those at Alum Creek have an angle of 40° and point downwards. The surfaces of the cones are fluted and show evidences of movement. Tarr concludes that they are due to a combination of pressure and solution, the clayey matter of the dissolved limestone being left behind between the shells. This removal facilitated the movement of the cones on each other. Tarr suggests that the pressure may have been due to the expansion resulting from the change of the calcium carbonate from aragonite to calcite, with its resultant increase of volume.

One sometimes gets the impression that the sedimentary rocks are well understood. "They are old sea-bottom deposits of sand, mud, or lime mud." So far, so good. But the moment one begins to ask closely concerning the meaning of detailed structures it is clear that

[1]Loc. cit., p. 91.
[2]Tarr, W. A., Cone-in-cone. Am. Jour. Sci. Vol. 204, pp. 199–213, 1922. An excellent summary of the subject.

while some things are known, many things are not known. This is emphatically true of several subjects discussed above, such as the non-organic calcite of limestone, dolomitization, concretions, cone-in-cone. The list might be almost indefinitely extended. It is well to know this; to be conscious of the fact that geology is a progressing science, and that no geological report can be final, or anything else than a "report of progress."

Mineralogy

In unaltered sediments like the bed-rocks of Delaware County the minerals are few. The following list includes those which can be seen without the use of the microscope. The list could be extended if accessory minerals in the sandstones and the minerals of the clays were included.

Calcite, $CaCO_3$. Occurs as the chief mineral in the limestone, and as more coarsely crystallized material in the limestone and in the Ohio shale concretions, also in fissures in the limestone.

Dolomite, $(CaMg)CO_3$. Usually as small rhombic crystals in the limestone, increasing in amount until in certain layers, as in the Bellepoint member, it makes almost the whole rock.

Quartz, SiO_2. In sandstones, as scattered grains in the limestones, and as a fine-grained variety making the chert in the limestone.

Pyrite, FeS_2. In grains and small granular aggregates in the limestone, but much more abundantly in the shale. Crystals show cube, pyritohedron and cube-octahedron in combination.

Marcasite, FeS_2. Difficult to distinguish from pyrite when not in crystals. In grains and masses in the limestone and shale. Groups of twinned crystals are found in the Olentangy shale.

Melanterite, Copperas, $FeSO_4.7H_2O$. Forms on the surface of marcasite nodules when exposed to air. Deposited on the face of shale banks by evaporation of escaping ground water. Origin in the oxidation and hydration of the iron sulphide.

Gypsum, $CaSO_4\ 2H_2O$. Found on the parting planes of the Ohio shale as minute, flattened, elongated, white crystals, obliquely terminated. Origin in the reaction of the sulphuric acid, produced by the oxidation and hydration of the sulphur of the iron sulphide, on the calcium carbonate in solution in the ground water.

Barite, $BaSO_4$. Has been found in the broken and recemented cores of some limestone concretions in the Ohio shale.

Limonite, $2Fe_2O_3.3H_2O$. Occurs as deposits about springs, and as stains and rusty discolorations in places on all the rocks. Origin in the oxidation and hydration of the iron sulphide.

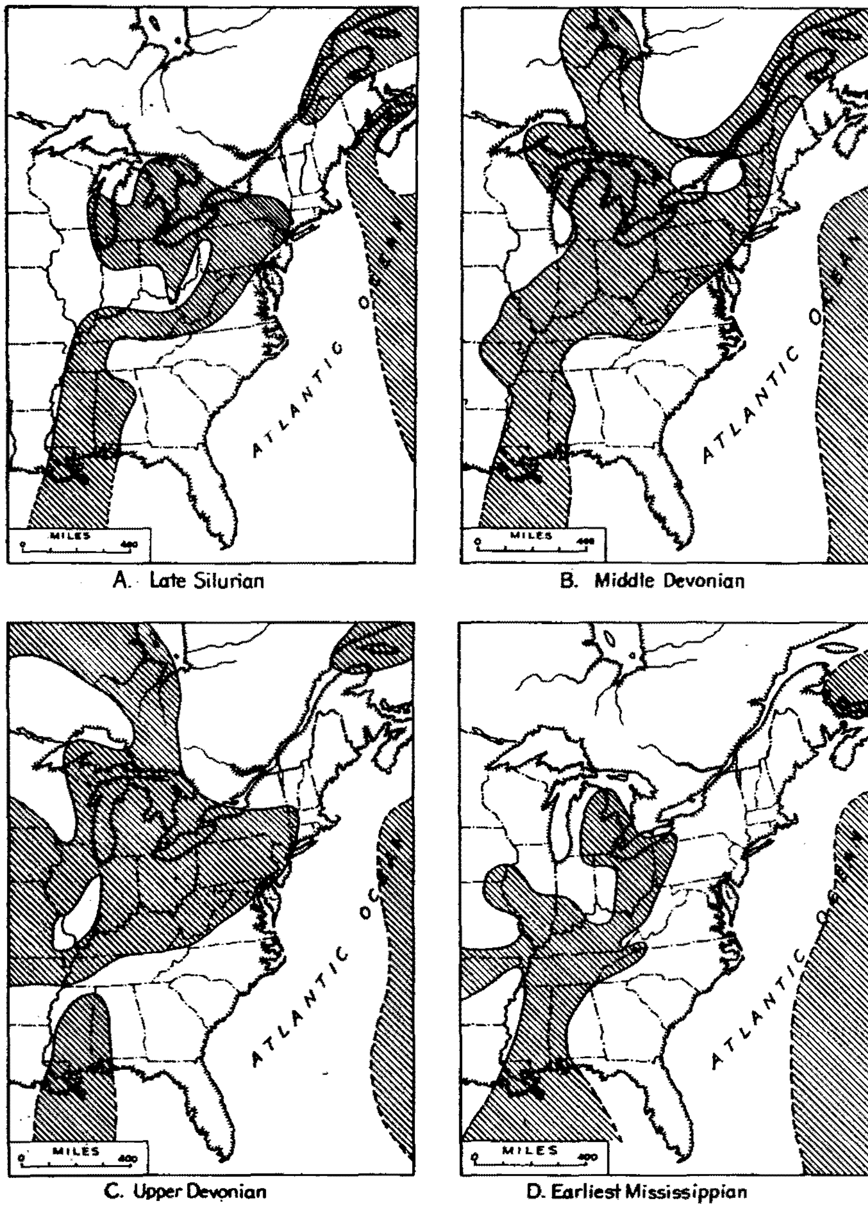
Geological History

The physical character of the Delaware County formations and their time equivalence have been considered in preceding sections. It is purposed here to give a brief review of the geographic changes of the county during the period of their accumulation—in other words, a sketch of the geological history of the county during that time.

The bed-rocks of the county are all marine sediments; they were laid down in ancient seas. It must not be assumed that because central Ohio of that time was under the surface of the sea, the waters of that sea had the great depths of the mid-ocean at the present time. The ocean bottom today slopes gently away from the present shore line to a depth of about 100 fathoms or 600 feet; thence the slope is much steeper until at a depth of between two and three miles the immense monotonous plains of the ocean abyss are reached. The 100-fathom line rather than the present shore line is thus in a large structural sense the border of the continent; it separates the deeper waters of the continental slope and ocean abyss from the shallow waters covering the continental shelf, which lies between the present shore and the 100-fathom line. These shallow seas are called epicontinental seas. Where they border the continent, as they do along the Atlantic coast of Eastern America for a distance out of 100 to 150 miles, they are shelf seas. In places they push their way far into the continent as does Hudson Bay, which has a mean depth of 420 feet. The Baltic and North seas of Western Europe are similar shallow seas. The Devonian seas of the Ohio Valley are to be compared to the present Baltic and North seas of Europe and Hudson Bay of America; they were shallow, epicontinental seas. They are not to be compared with the Gulf of Mexico, which is a deep-water invasion of the continent by the ocean abyss. The maps (Fig. 16) show the position of these seas at different periods of the middle Paleozoic.

The proof of the shallow depths of these Paleozoic seas is found in their abundant plant and animal life, current-made ripple marks, and local unconformities, not only in the sandstones but occasionally in the limestones, and in the frequently worn character of the fossil remains. The ordinary maximum depth may have been not more than 200 to 300 feet.

The sea areas of the past are mapped by including in them the observed outcrops and inferred former occurrences of the marine formations of the period, whether the latter are now buried or have been removed by erosion, and by connecting these areas with each other or with the main oceans as may best account for the similarities or unlikenesses of the fossils of the different known rock areas. The character of the land areas is a matter of inference from the sediments. Pure limestones mean that no mechanical sediments were being brought from the land; which might be due either to great distance from land or to the near-by land areas being low and flat. Abundant sands and gravels would mean abundant mechanical sediment, swifter streams, and higher lands.



A. Late Silurian

B. Middle Devonian

C. Upper Devonian

D. Earliest Mississippian

Fig. 16. Paleogeographic maps of the eastern half of the United States. (After Schuchert)

The water areas of late Silurian (Monroe) time are shown in Fig. 16-A[1]. A large interior sea covered most of Ohio, and extended north into Michigan and Ontario. It is shown connecting with the open ocean near New York. Before the end of the Silurian sufficient elevation took place to drain this sea, and central Ohio did not again sink beneath the sea until the beginning of the Middle Devonian (Columbus or Onondaga). The geography of that time is shown in Figure 16-B. An inland sea stretches from Ohio north across Canada to Hudson Bay, to include certain Devonian formations found there with fossil forms similar to those in Ohio; it extends east across New York and Pennsylvania, and northeast along the St. Lawrence to the Atlantic.

A land barrier was formerly shown between the two areas of Delaware limestone in Ohio and Indiana, but the present map shows the interior sea extending as a wide waterway southwest across Ohio, Indiana, Kentucky, and southern Illinois, and thence south to the Gulf of Mexico. The nearest land to Delaware County was to the southeast, in Virginia and the Carolinas. Of the height of this land to the southeast not much can be said; it was probably moderate. Muds were washed from it into that part of the sea in northwestern Virginia, but little or no mechanical sediment reached central Ohio.

This inland sea continued in central Ohio throughout Columbus and Delaware time though its outlines in Eastern North America were doubtless constantly shifting. The much larger percentage of clayey material in the Delaware shows muddier waters towards the end; this may have been due to shallowing of the sea or to slight elevation of the adjacent land areas leading to increased sediment carried by streams.

If we are correct in placing an unconformity between the Delaware and Olentangy formations (see p. 33), the Ohio sea again disappeared at the end of Middle Devonian time and a period of low land areas and erosion followed. Later, in Upper Devonian time, the sea returned and continued, with one slight interruption just before the Berea, to the end of the period represented by the youngest rocks of the county. The geography of this Upper Devonian time, during which the Ohio shale was forming, is shown in Fig. 16-C. Conditions in Ohio were not greatly different from those of mid-Devonian; the eastern half of the

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[1]Professor Charles Schuchert of Yale University has done more than any other American geologist in accumulating and presenting the facts of the ancient geography of North America. These were first brought together in his great work *Paleogeography of North America*, Bull. G. S. A. Vol. 20, pp. 427–606, pls. 46–101, 1910. Plates 51 to 100 of this work are a series of North American paleogeographic maps covering the whole of geologic time from the Cambrian to the Pliocene. These maps have been constantly revised in the light of later knowledge and some of them are given in their latest form in Pirsson and Schuchert, *Text-Book of Geology*, Part II, Historical Geology, 2nd edition, 1924. It is interesting, as showing changing opinion, to compare the maps of any single period, say the Onondaga (Columbus) in these two publications issued fourteen years apart. It suggests that they can be approximate only and that even the latest maps are subject to change in the light of new information. The maps (Fig. 16) have been revised by Professor Schuchert.

State was under the waters of a sea larger than at any earlier period of the Devonian, with the nearest land 200 miles southeast in Virginia. But the conditions to the southeast were markedly different. Probably rising lands were responsible for increased stream flow. The lowland surface, deeply covered with residual clays, furnished abundant muddy sediment to the streams and there began that deposit of shales (Olentangy, Ohio, Bedford, Sunbury, and the shaly part of the Cuyahoga) which makes the upper part of the rocks of Delaware County. In these muddy waters animal life was scanty and limestone formation was no longer possible.

The unconformity at the base of the Berea (see p. 42) represents a period of land elevation, probably much shorter than those represented by the unconformities at the base of the Columbus and top of the Delaware. After the resubmergence, the deposition was more sandy; it started with the Berea sandstone, was interrupted by the muddy sediments of the Sunbury, and was continued in the sands and sandy shales of the Cuyahoga. The geography of this early Mississippian time is shown in Figure 16-D.

Life Record

INTRODUCTORY

Geology is the history of the earth. The geologist is interested not only in the physical history of the earth, its geographies, climates, etc., but in the floras of the successive periods and in the animal life of its lands and waters. Any remains of plants or animals found in the rocks are *fossils*. The bed-rocks of the county are all old sea bottom deposits, and so contain marine fossils. The limestones are crowded with them and one, the Columbus limestone, has long been classic ground for collectors. Because the bed-rocks are all marine, land plants and animals are rare and fossils of land animals are unknown in them. Land plants are represented by logs, stems, and other parts, which fell into the streams, were swept out to sea, and, becoming waterlogged, sank and were buried in the bottom muds.

Fossils have several uses for the geologist. Some of them are so characteristic of particular formations, or even of particular levels or horizons within a formation, that one acquainted with them knows at once on finding them where he is in the rock series. These are *guide* or *index fossils*. Again, just as today different environments harbor different assemblages of plants and animals; just as the ocean, fresh water lakes, rivers, and the land surface have different and characteristic kinds of plant and animal life, so it has been in every period of the past and fossils can be used to interpret past conditions. We know at once from the presence of corals, trilobites, and brachiopods, forms that are today limited to marine waters, in the Columbus and Delaware limestones, that these rocks were laid down in an old inland sea. Further, apart from any uses toward other ends that the fossils may have they have interest in themselves as part of that great ongoing evolutionary process which has culminated in the present plant and animal life of the earth, of which we ourselves are a part.[1]

THE VERTICAL DISTRIBUTION OF FOSSILS

Evolution and migration

It was early recognized that in a series of sedimentary rocks any bed or formation is younger than those underneath and older than those above. This is the law of superposition. Over a century ago William Smith in England and Cuvier and Brongniart in France discovered independently that each successive rock formation had its own characteristic assemblage of fossils and that when the relative age of the formations had once been determined by superposition, the fossils could thereafter be used to identify the formations and determine their age. Nearly seventy years ago Darwin, by his publication of the *Origin of Species*, gave new life to the Theory of Descent or Evolution. We can now see why through successively higher and hence younger formations the organisms should differ; it is because there has been a progressive development in the organic world so that the life of no period of the world's past has been like that of any other period.

Yet when we study the vertical distribution of fossils in a rock series of limited thickness, like the 125 feet of Columbus and Delaware limestones, we do not find the gradual changes in life which we might expect as a result of evolutionary development. Changes there are, frequent and drastic, that cannot be explained by the development of the forms in the higher beds from those in the lower. Specific examples will make this clear. The first abundant fossiliferous horizon of the Columbus limestone is the coral layer, 30 feet above its base. Here for five or six feet, are immense numbers of corals and stromatoporoids in places making up almost the entire mass of the rock, and forming a veritable

[1]The detailed study of fossils is not a simple matter. There is no easy key to their identification, as there are keys for birds and flowering plants. The nearest to this kind of a book is Grabau, *North American Index Fossils*, in two volumes; and this deals with only the most outstanding species, covers all the periods and all of North America, and often does not happen to describe the common forms which one actually meets. The best short introduction is Shimer, *An Introduction to the Study of Fossils*, which gives a good general account of the groups of plants and animal fossils.

When it comes to the identification of the local forms in our Devonian rocks a small library is needed. Stauffer, Bulletin 10, Geological Survey of Ohio, *The Middle Devonian of Ohio*, gives the lists of species. One can then begin with the two volumes of the *Paleontology of Ohio*, or with Vol. 7 of the *Geology of Ohio*, all of which have descriptions of some of our Devonian fossils. Kindle, *The Devonian Fossils and Stratigraphy of Indiana*, in the Twenty-fifth Annual Report of the Department of Geology and Natural Resources of Indiana, helps; for the same Devonian formations as those in Ohio are found in Indiana with much the same kind of fossils. Then one goes to the great series of reports on the Paleontology of New York, Vols. 4 and 8, Parts 1 and 2, for brachiopods; Vol. 5, Part 1, for lamellibranchs; Part 2, for gastropods and cephalopods; Vol. 6, for corals and bryozoa; and Vol. 7 for trilobites. And when all that is done it is surprising and irritating to note the number of forms still unknown or doubtfully known.

coral layer. But they appear suddenly with no inkling in the underlying Bellepoint member of either their coming abundance or variety. This lack of warning may be in some small part due to the fact that the Bellepoint member is a dolomite and has lost its original fossil remains. But in the main it is due to the fact that the coral fauna came into this area from outside, from some other part of the Devonian sea. They are immigrants, not native sons. They did not develop out of earlier forms living here. Nor do the corals and stromatoporoids maintain either their abundance or their kinds in the rocks above. A few species hold on, but the mcst characteristic do not. So that we have extinction, in this locality at least, to account for as well as appearance. And the extinction is harder to account for than the appearance. Why, having once secured a foothold and an abounding growth, should they die out?

Another level at which marked changes take place in the fossil forms is near the top of the Columbus limestone. A few feet below the bone bed, which is taken as the boundary between the Delaware and Columbus limestones, the brachiopod *Spirifer acuminatus* comes in. It is found through several feet of the Columbus, but is absent from the Columbus below and does not pass up into the overlying Delaware. It is an interesting fact that in the upper Columbus on Lake Erie *Spirifer acuminatus* occurs at two levels, separated by beds in which it is not found. Here we have two invasions. The earlier immigrants maintained themselves for a short time and then for some unknown reason died out. That they did not die out in their original home is proved by the second invasion, and this later invasion, unlike the first, reached central Ohio and gave us the species in the beds just below the bone bed. *Spirifer duodenarius* and a crinoid, *Nucleocrinus*, are other forms found just below the bone bed and limited to two or three feet vertically. Above the bone bed there is a marked contrast in the fauna with the underlying Columbus. *Delthyris consobrinus*, *Leptaena rhomboidalis*, and *Tentaculites scalariformis*, the last two sparingly present in the Columbus, come in in great numbers and continue through most of the Delaware. Opening of distant land barriers, or slight changes in local marine conditions (for Delaware waters were muddier than those of Columbus time) favored migration and changes in species in the local fauna.

The history of the Delaware region is part of the world history of Devonian time, and just as the varying human population of the county in the last four hundred years cannot be understood without a knowledge of the history of the rest of America, and even of Europe, no more can the geological story of the county be understood without a corresponding wider knowledge of the geology of the time.

The practical result of these immigrations is that different layers of the formation in any region contain characteristic fossil immigrants by which they may be recognized. These are the index or guide species mentioned above. They may belong to any animal group. In the

Devonian limestones they are commonly corals and brachiopods, partly because these are the most abundant groups and in part because it is easier to recognize species in these two groups than in groups like the lamellibranchs and gastropods where the specific differences are less marked.

It should not be assumed from the foregoing discussion that no gradual evolutionary changes in organisms are to be found even in such a limited vertical series of beds as the Middle Devonian limestones. None have been reported yet from the Ohio Devonian; probably because they have not been sought. It is likely that such evolutionary lines, genetic series, can be found for the medium-sized spirifers of the Columbus and Delaware. But for purposes of identification of beds, such evolutionary and so gradual changes are of little value compared with the sudden changes due to migration.

Character of sediments

More marked than any life changes within the limestones is the change which takes place in passing from the limestones into the overlying shales. These are almost wholly lacking in animal fossils. A few small brachiopods (*Lingula* and *Discina*), occasional crinoid fragments, minute "conodonts" (worm teeth?) are the only invertebrate forms, a sorry contrast to the abounding life of the underlying limestones. Large fishes and abundant plant remains are found. But the abundant invertebrate fauna of the underlying limestones is absent. The reason for this lies in the different bottom conditions under which the two formations were laid down. The seas of Columbus time were free of mud and favorable to abundant life, and the same was largely true of Delaware time. But the Upper Devonian shales prove muddy seas; and in those muddied waters the prolific animal life of the Middle Devonian was impossible. The presence of some crinoidal and fish remains in the concretions in the Ohio shale and not elsewhere in the formation suggests that the barrenness in fossils of the shale may be due in part to failure to preserve the fossil remains in the main mass of the rock; but this is probably a minor consideration.

COMPARISON OF COLUMBUS AND DELAWARE FAUNAS

The following table, compiled from Stauffer,[1] shows the contrast in life between the Columbus and Delaware limestones:

Group	No. of species in Columbus limestone	No. of species in Delaware limestone	Total species in both formations
Rhizopods	1	0	1
Sponges	1	0	1
Corals	47	10	49

[1]Geol. Survey Ohio, Bull. 10, pp. 160–170.

Group	No. of species in Columbus limestone	No. of species in Delaware limestone	Total species in both formations
Hydrozoa	7	2	7
Crinoids	11	2	11
Blastoids	2	1	3
Bryozoa	23	12	30
Brachiopods	67	53	94
Pelecypods	38	22	54
Gastropods	76	11	78
Pteropods	3	2	4
Cephalopods	31	8	34
Crustaceans	14	4	15
Fishes	16	14	20
Total	337	141	401

Some interesting facts are brought out from an inspection of this table. Most striking is the much larger number of species found in the Columbus limestone. This is true not only for the total but for every group. An examination of the two formations in the field shows that the same is true for the number of individuals. The Columbus limestone contains a much larger proportion of recognizable organic remains in its make-up, a smaller proportion of non-organic matrix. The Delaware sea was less favorable to organic life than was that of Columbus time. Various factors may have contributed to this but perhaps the most important was the greater muddiness of the Delaware sea, proved by the much larger amount of clayey material in the Delaware limestone.

The table shows that the most abundant groups are the brachiopods, gastropods, pelecypods, and corals. The Columbus list is in a way packed for the gastropods; their large total being mainly due to the large number of forms found in a single cherty horizon, the Eversole chert, Zone D, near the south boundary of the county.

FISHES[1]

The Devonian has been called the Age of Fishes. For the first time in the history of the earth fishes were abundant; they were the largest and most formidable animals of the period, dominating the life of its seas. Stauffer[2] lists twenty species from the Columbus and Delaware limestones. Still others are found in the Ohio shale, and the rocks of Delaware County have contributed more than their share.

Four of the six sub-classes of the class Pisces (Fishes) as given by Zittel-Eastman[3] follow:

[1]Descriptions of the Devonian fishes by Newberry are found in the Geological Survey of Ohio, Vol. 1, Part 2, Paleontology, pp. 290–324, pl. 24–35, 1873, and in U. S. Geological Survey, Monograph XVI, The Paleozoic Fishes of North America, 1889.
[2]Geol. Survey Ohio, Bull. 10, p. 169.
[3]Textbook of Paleontology, Vol. 2, p. vii.

Selachians. Shark-like forms
Arthrodira
Ganoids
Teleosts. Bony fishes

Of these the Teleosts are the bony fishes, with bony interior skeleton, comprising the vast majority of present-day fishes. But teleosts were not in existence in Devonian time. The forms of that time, belonging to the other groups listed, had a cartilaginous and not a bony internal skeleton; their hard preservable parts were the jaws, teeth, scales, spine-like fin-rays, and external plates covering the head and forward part of the body. These separated on the death of the animal and were scattered; whole fish are rarely if ever found in our local Devonian rocks.

One of the Selachians (sharks), *Machaeracanthus*, is represented by single spines, believed to be fin-rays. The most common form in the limestones is *Onychodus sigmoides* Newberry, a ganoid. The parts preserved are scales, head plates, jaws, set with small conical teeth, and furnished in front with a cluster of large curved tusk-like teeth, which reach two inches in length. The jaws often reach a length of over a foot and the fish itself can have been hardly less than five or six feet long.

More formidable than *Onychodus* was *Dinichthys* (meaning mighty or terrible fish), the remains of which are found in the Ohio shale. The head was sometimes over three feet long and the total length is estimated by Newberry at from 10 to 15 feet. *Dinichthys* was a large-jawed creature, the head and forward part of the body was covered with heavy plates, and altogether it deserved the name Newberry gave it.

Dinichthys hertzeri was first obtained from the limestone concretions in the Ohio shale at Delaware and the manner of its finding is described by Newberry:[1]

"Our first knowledge of *Dinichthys Hertzeri* we owe to the industry and acuteness of observation of Rev. H. Hertzer, a clergyman stationed for two years at Delaware, Ohio; and who, while performing his ministerial duties, and receiving a very small salary, still found time to make many important collections and observations in geology. The town of Delaware is located upon the line of junction of the Huron (Ohio) shale and the Hamilton and Corniferous (Delaware and Columbus) limestones. The Corniferous abounds in fossils, and Mr. Hertzer collected a splendid suite of the ichthyolites which characterize this formation; but the Huron shale had, up to this time, been regarded by all geologists as barren ground—nothing but a few *Lingulae* and *Discinae* having been obtained from it. Near its base the Black shale contains, both at Delaware and elsewhere, a great number of concretions composed of impure limestone. These are often quite spherical, and ten feet or more in diameter. In examining some of these septaria which had been split, apparently by the frost, Mr. Hertzer discovered that they not unfrequently contained masses of silicified wood (*Dodoxylon Newberryi*, Dawson) or fragments of bones that had served as nuclei

[1]Geol. Surv. Ohio, Vol. 1, Part 2, Paleontology, p. 320.

around which they had formed. Of these bones several were taken by Mr. Hertzer to the meeting of the American Association at Buffalo, in 1866. There they were submitted to me, and I recognized them as the bones of huge Ganoid fishes, altogether new to science. With enthusiasm fired anew by the interest these specimens excited, Mr. Hertzer devoted all the time possible to further examinations of the concretions which contained them. The rock which contains these fossils is one of the toughest and most intractable known, and Mr. Hertzer deserves great credit for the care and skill with which hundreds of fragments were carefully gathered, and each cemented in its proper place. In one of these concretions Mr. Hertzer found a head of *Dinichthys*, of which the component parts, though somewhat dislocated, were all present. In another was a complete mandible, and in still another, one of the great teeth of the upper jaw. Though much broken, both of these latter specimens were restored by Mr. Hertzer nearly to their former integrity, and they now constitute the pride of the collection of the School of Mines of Columbia College."

Scattered teeth and other fish fragments are found throughout the limestones and at two levels are so abundant as to constitute a bone bed. The more wide-spread of these has been taken as marking the top of the Columbus limestone. It is well shown in the quarries west of Columbus, but is much less distinct in Delaware County. The other, the only one which is well shown in Delaware County, is nearly at the top of the Delaware limestone, in an old quarry west from the Hocking Valley Railway, near the station, at Delaware. The fish fragments lie in a crinoidal limestone layer just above a small unconformity; their concentration may be due to wear during the production of the unconformity.

COMMON FOSSILS

The more common fossils of the limestones are given in the following list, in which the names are those used in Bulletin 10 of the Geological Survey of Ohio:

MONROE LIMESTONE

Only a few feet of the Monroe shows in the county, and the rock is a dolomite. The fossils are usually in the form of imperfect and nearly unrecognizable casts.

Brachiopods
- Meristella bella Hall.
- Spirifer vanuxemi Hall.

Crustaceans
- Leperditia alta Conrad.

THE COLUMBUS LIMESTONE

Corals
- Cystiphyllum vesiculosum Goldfuss.
- Diphyphyllum verneuilianum (Edwards and Haime).

Favosites hemisphericus (Troost).
Favosites basalticus Goldfuss.
Heliophyllum corniculum (Lesueur).
Heliophyllum halli Edwards and Haime.
Synaptophyllum simcoense (Billings).
Zaphrentis gigantea Lesueur.
Zaphrentis prolifica Billings.

Echinoderms
Nucleocrinus verneuili (Troost).

Bryozoa
Cystodictya (stictopora) gilberti (Meek).

Brachiopods
Atrypa reticularis (Linnaeus).
Chonetes mucronatus Hall.
Cyrtina hamiltonensis Hall.
Leptaena rhomboidalis (Wilckens).
Meristella nasuta (Conrad)
Rhipidomella vanuxemi Hall.
Schizophoria propinque Hall.
Spirifer acuminatus (Conrad)
Spirifer duodenarius (Hall).
Spirifer gregarius Clapp.
Spirifer macrothyris Hall.
Spirifer manni Hall.
Stropheodonta demissa (Conrad).
Stropheodonta hemispherica Hall.
Stropheodonta perplana (Conrad)
Strophonella ampla Hall.

Pelecypods (Lamellibranchs).
Aviculopecten princeps (Conrad).
Conocardium cuneus (Conrad).
Modiomorpha concentrica (Conrad).
Mytilarca percarinata Whitfield.
Paracyclas elliptica Hall.

Gastropods
Bellerophon pelops Hall.
Callonema bellatulum (Hall.)
Loxonema pexatum Hall.
Platyceras dumosum Conrad.
Pleuronotus decewi (Billings.)
Turbo shumardi DeVerneuil.

Pteropods
Tentaculites scalariformis Hall.

Cephalopods
Gomphoceras eximium Hall.
Gyroceras cyclops Hall.
Orthoceras thoas Hall.

Crustaceans (Trilobites)
Chasmops anchiops (Green)
Phacops cristata Hall.
Proetus rowi (Green).

DELAWARE LIMESTONE

The commoner fossils of the Delaware are:

Corals
- Hadrophyllum d'Orbignyi Edwards and Haime.

Echinoderms
- Nucleocrinus.

Bryozoan
- Cystodictya (stictopora) gilberti (Meek).

Brachiopods
- Camaratoechia prolifica Hall.
- Chonetes deflectus Hall.
- Delthyris consobrina (d'Orbignyi).
- Leiorhynchus limitare (Vanuxem).
- Leptaena rhomboidalis (Wilckens).
- Lingula manni Hall.
- Martinia maia (Billings).
- Orbiculoidea lodiensis (Vanuxem).
- Rhipidomella vanuxemi Hall.
- Stropheodonta demissa (Conrad).
- Stropheodonta perplana (Conrad).

Pelecypods (Lamellibranchs)
- Aviculopecten princeps (Conrad).
- Grammysia bisulcata (Conrad).

Gastropods
- Platyceras erectum (Hall).

Pteropods
- Tentaculites scalariformis Hall.

Trilobites
- Phacops rana (Green).

Explanation of Plates

PLATE VI

MONROE LIMESTONE FOSSILS

Crustacean. Fig. 1.

Fig. 1. *Leperditia alta* Conrad. The most common fossil. It often looks like a small pebble in the rock.

COLUMBUS LIMESTONE FOSSILS

Corals. Figs. 2-11.

Fig. 2. *Heliophyllum corniculum* (Lesueur). This is one of the simple corals. It is sometimes called a cup or horn coral, because of its shape. It occurs throughout the formation but is probably more abundant in the upper part. It is usually smaller than the specimen figured.

Figs. 3, 4. *Zaphrentis gigantea* Lesueur. The largest of the cup corals, reaching a length of 2¼ feet and a diameter of 3 inches. Fig. 3 is a vertical section and shows the horizontal tabulae. Fig. 4 is a cross section showing radiating septa of alternating length.

Figs. 5, 6, 7. *Synaptophyllum simcoense* (Billings). A branching, compound or colonial type. Structurally each tube in Fig. 5 corresponds to the single forms of Figs. 2-4. Fig. 6 is a vertical section of one of the tubes; Fig. 7 a cross section. Common in the coral layer.

Figs. 8, 9. *Favosites basalticus* Goldfuss. This is a colony form. Fig. 8 is a vertical section and Fig. 9 a cross section of a single polyp. In Fig. 8 two tabulae (at the upper end), squamulae or horizontal, tongue-shaped plates (in the middle), and pores (on the outside of the corallites at the lower end) are shown. The individual stems or corallites are in contact and so take a roughly hexagonal shape. Some species of *Favosites* in the Columbus limestone make masses over two feet in diameter.

Figs. 10, 11. *Hadrophyllum d'Orbignyi* Edwards and Haime. Sometimes called "button coral." A simple coral. A characteristic species of a zone near the top of the Delaware limestone, but included here with the other corals. Figs. 10, upper view; Fig. 11, side view.

Blastoid. Fig. 12.

Fig. 12. *Nucleocrinus verneuili* (Troost). An echinoderm, shaped like a nutmeg, and found just below the top of the Columbus limestone.

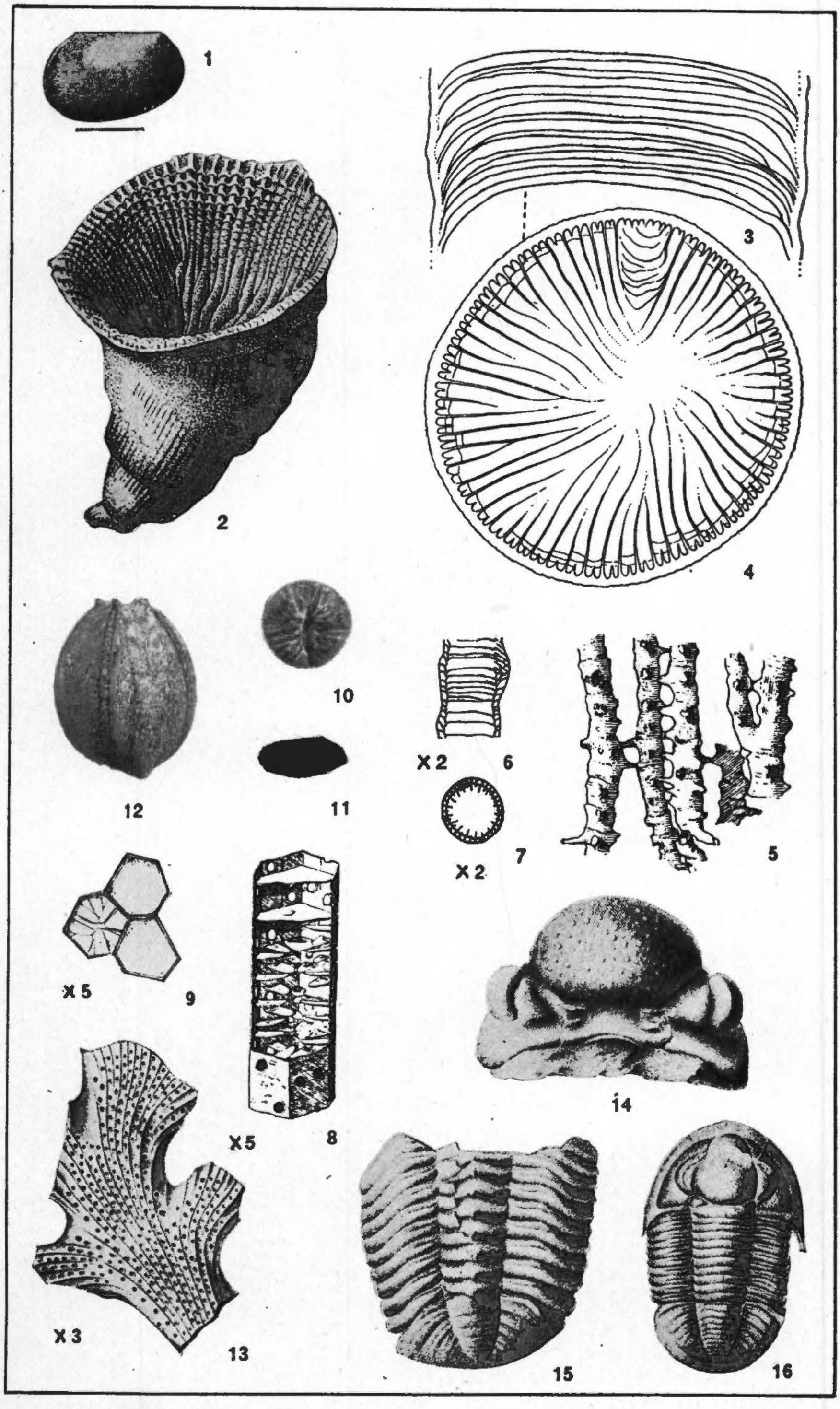
Bryozoan. Fig. 13.

Fig. 13. *Cystodictya (Stictopora) gilberti* (Meek). Common in both Delaware and Columbus limestones.

Crustaceans (Trilobites). Figs. 14-16.

Figs. 14, 15. *Phacops cristata* Hall. Common. The form is ringed or segmented and usually breaks up on death so that the head (Fig. 14) and tail-piece (Fig. 15, lower part) are found separate. Usually only the head is found.

Fig. 16. *Proetus rowi* (Green). Abundant in the Columbus limestone.



Monroe and Columbus limestone fossils.

PLATE VII

COLUMBUS LIMESTONE FOSSILS

Pelecypods. Figs. 1-2.

Fig. 1. *Paracyclas elliptica* Hall. This is a common and easily recognized fossil, occurring throughout the formation. Found also in the Delaware.

Fig. 2. *Conocardium cuneus* (Conrad). This fossil usually occurs as a cast of the interior of the shell. It is one of the most striking fossils of the formation.

Gastropods. Figs. 3-4.

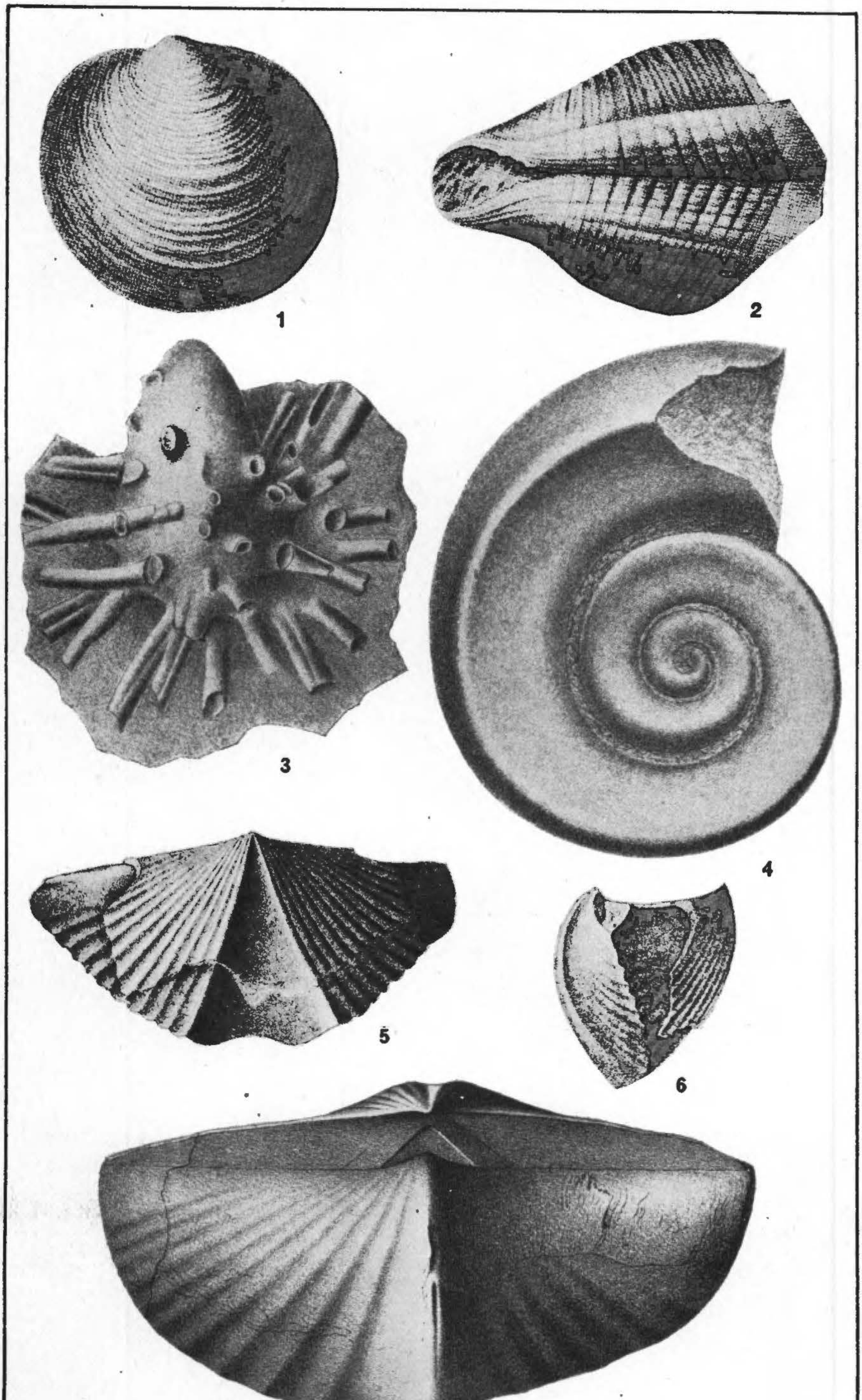
Fig. 3. *Platyceras dumosum* Conrad. It is a common fossil in the upper ten feet of the formation, just below the bone bed.

Fig. 4. *Pleuronotus decewi* (Billings). A very common cast. It is rarely preserved with the shell, and yet it is readily recognized. The coil is nearly in a single plane. Common in the Columbus; occasionally found in the Delaware.

Brachiopods. Figs. 5-7.

Figs. 5, 6. *Spirifer manni* Hall. Common in the Klondike member of the Columbus. The high beak of the ventral valve is characteristic. Fig. 5 is a view of the ventral valve; Fig. 6 an end or side view.

Fig. 7. *Spirifer macrothyris* Hall. This is the largest Spirifer found in the Devonian limestone of the county. It is characteristic of the layers above the coral layer.



Columbus limestone fossils.

PLATE VIII

COLUMBUS LIMESTONE FOSSILS

Brachiopods. Figs. 1-19.

Figs. 1, 2. *Schizophoria propinque* Hall.

Figs. 3, 4. *Stropheodonta perplana* (Conrad.) Common in Columbus; also in the Delaware.

Figs. 5, 6. *Productella spinulicosta* Hall. Usually this fossil shows long spines projecting from the surface. This genus differs from Productus of the later formations, in that it has hinge teeth. The genus makes its first appearance in the Middle Devonian. Also in the Delaware.

Fig. 7. *Stropheodonta hemispherica* Hall. Common in Columbus; occasionally in the Delaware.

Fig. 8. *Reticularia fimbriata* (Conrad). The fimbriate structure shows well under a magnifying glass.

Figs. 9, 10. *Chonetes mucronatus* Hall. Note the spines projecting from the pedicle valve along the upper margin of the cardinal area. Also in the Delaware.

Fig. 11. *Atrypa reticularis* (Linnaeus). One of the most abundant fossils.

Fig. 12. *Pholidostrophia iowaensis* (Owen). In both Columbus and Delaware.

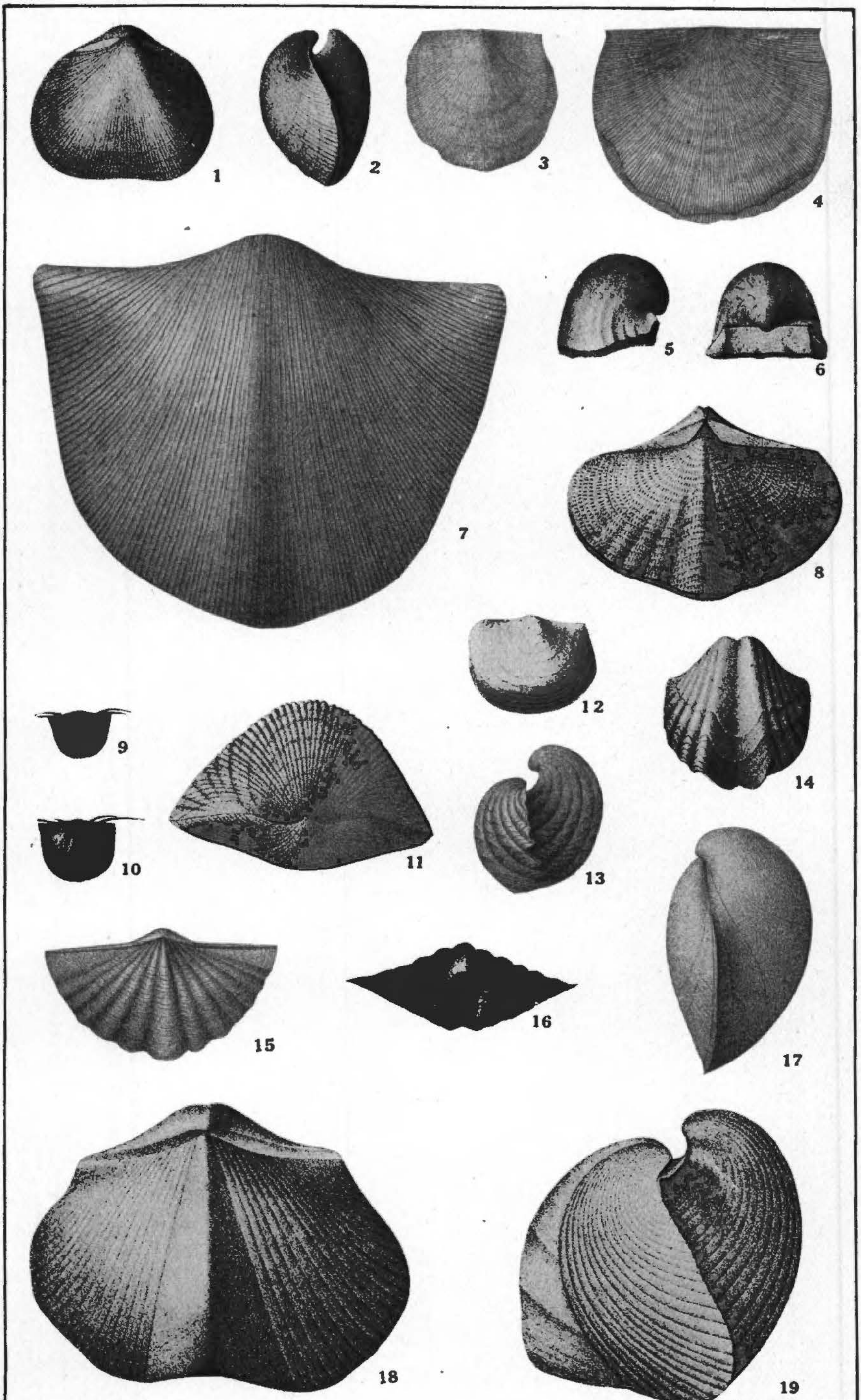
Figs. 13, 14. *Spirifer gregarius* Clapp. A common fossil in this formation. About thirty-two feet below the bone bed, it occurs in great numbers.

Figs. 15, 16. *Spirifer duodenarius* (Hall). This fossil occurs only at the upper boundary of the formation in central Ohio. It, as also the preceding, belongs to the primitive simple plication type of Spirifer.

Fig. 17. *Meristella nasuta* (Conrad). A smooth spire-bearing shell, which occurs most abundantly in the lower part of the Eversole chert.

Figs. 18, 19. *Spirifer acuminatus* (Conrad). This Spirifer is almost entirely limited to the upper five or six feet of the formation in the region here discussed. Note that its costae or ribs bifurcate, a characteristic of the more advanced species of the genus.

PLATE VIII



Columbus limestone fossils.

PLATE IX

DELAWARE LIMESTONE FOSSILS

Brachiopods. Figs. 1-17.

Figs. 1, 2. *Orbiculoidea lodiensis* (Vanuxem).

Fig. 3. *Lingula manni* Hall. These two fossils occur in the shaly basal portion of the formation. Their shells are composed of phosphate of lime, as is so frequently the case in shells occurring in black shale.

Fig. 4. *Lingula ligea* Hall. Abundant in a zone near the middle of the formation.

Fig. 5. *Rhipidomella vanuxemi* Hall. In both Delaware and Columbus.

Fig. 6. *Stropheodonta demissa* (Conrad). Also in the Columbus.

Figs. 7, 8. *Leiorhynchus limitare* (Vanuxem). This is a characteristic fossil of the Marcellus shale, and common in the shaly partings of the Delaware.

Fig. 9. *Leptaena rhomboidalis* (Wilckens). This species, as at present defined, is one of the long-lived forms. It is found from the Trenton to the Waverly, but there is a difference in the forms from the two extreme ends. These, however, seem to grade into each other. Most abundant in the Delaware and found in the upper part of the Columbus.

Figs. 10, 11. *Delthyris consobrina* (d'Orbignyi). A common fossil of the formation. Note the zigzag concentric markings; unfortunately, these seldom show in specimens from the limestone.

Figs. 12, 13. *Martinia maia* (Billings).

Figs. 14, 15. *Chonetes deflectus* Hall. Compare this with the *Chonetes* figured among the Columbus limestone fossils.

Figs. 16, 17. *Cyrtina hamiltonensis* Hall. Found in both the Delaware and Columbus limestones.

Pelecypods. Figs. 18 and 19.

Fig. 18. *Pterinea flabellum* (Conrad). In both Delaware and Columbus.

Fig. 19. *Grammysia bisulcata* (Conrad). Note the ridge, with a furrow on either side, running from the beak to the margin. Characteristic just below the middle of the formation.

Gastropods. Figs. 20 and 21.

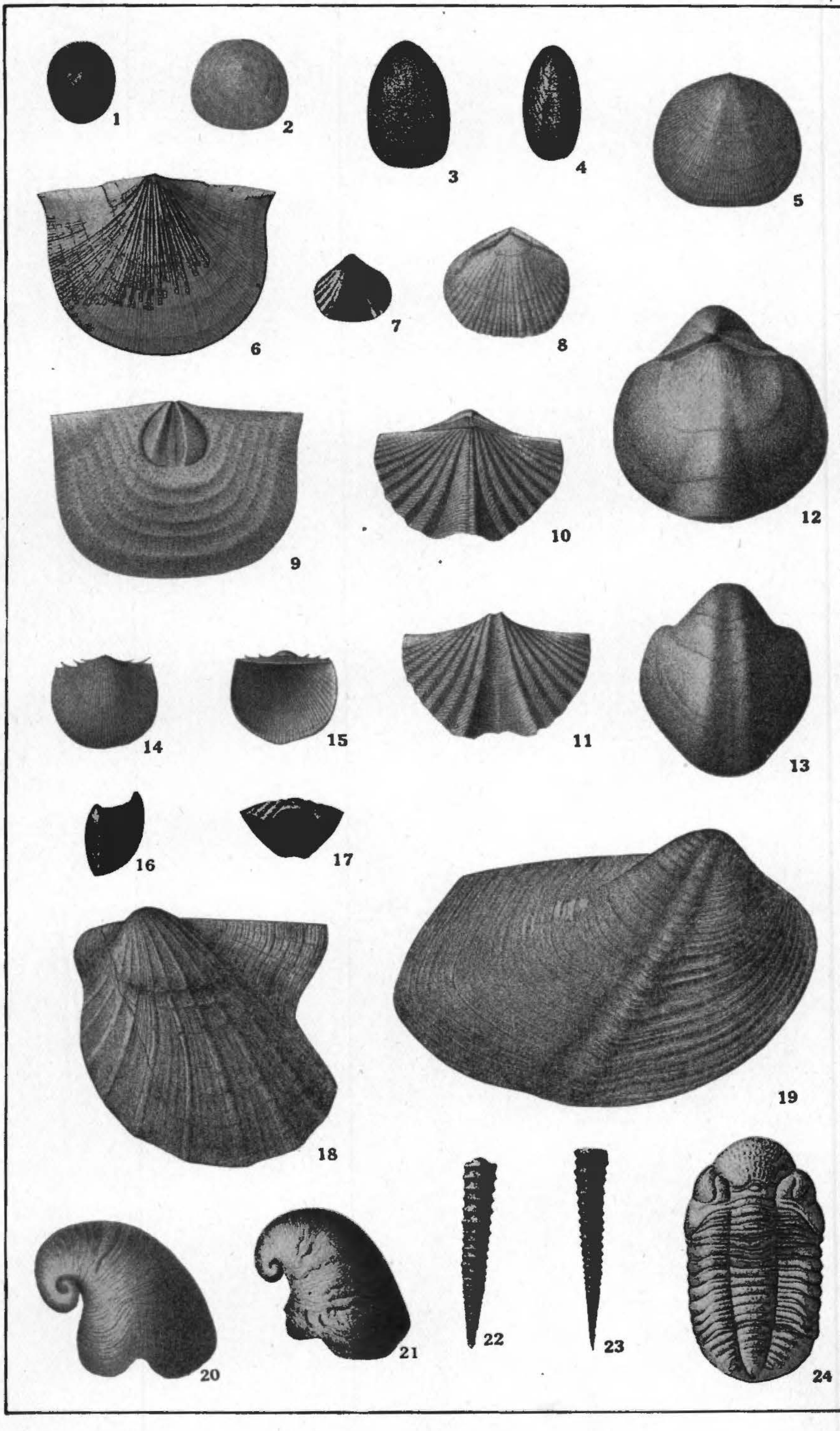
Figs. 20, 21. *Platyceras erectum* (Hall). Compare this species with the spiny one occurring in the Columbus limestone.

Pteropod. Figs. 22 and 23.

Figs. 22, 23. *Tentaculites scalariformis* Hall. This fossil is very frequent and readily recognizable.

Crustacean (Trilobite). Fig. 24.

Fig. 24. *Phacops rana* (Green).



Delaware limestone fossils.

CHAPTER III

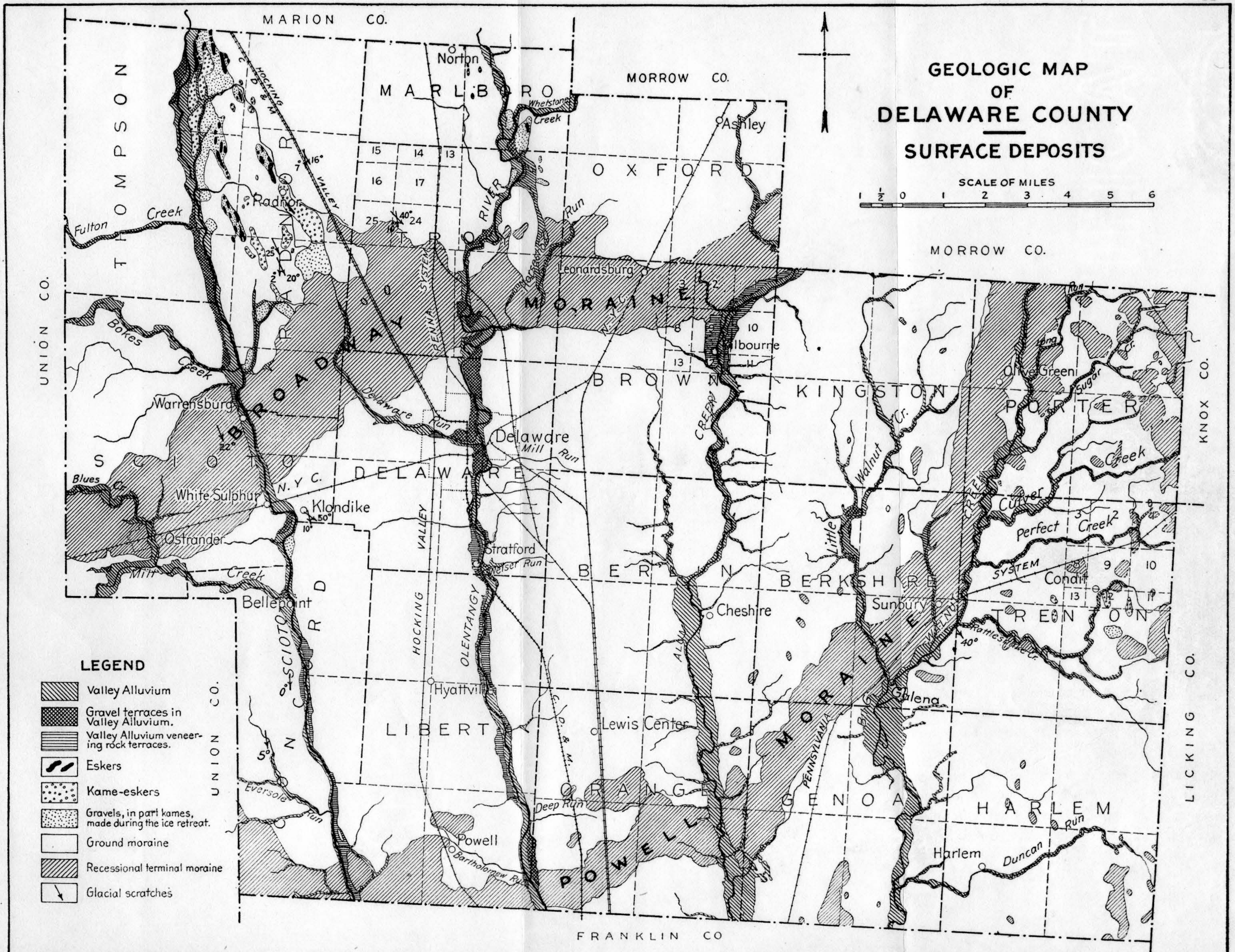
THE GLACIAL PERIOD

Introductory

The long period of stream erosion which followed the Appalachian mountain building was ended for northeastern America by one of the most striking events of geological history, the development of a succession of immense ice sheets or continental glaciers. The first of these inaugurated the Pleistocene or Glacial period. Starting from the merging of two independent sheets (Fig. 17), one west of Hudson Bay, the other east, the glacier moved out in all directions and on its southern side crossed into what is now New England and the upper Ohio and Mississippi valleys. At first geologists assumed, quite naturally, that there was but a single glacier; later studies have shown that instead of one there was a succession of glaciers—five are now recognized—each constituting a glacial epoch and leaving over the surface a deposit of clay and rock called a drift sheet or drift. Long interglacial periods separated these glacial periods; during some of these interglacial periods the climate was as mild or milder than that of today and the ice had probably disappeared from the lowlands of eastern North America.

Present day Greenland offers the nearest parallel to northern America of the Glacial period. It is an immense, monotonously level plain of snow-covered ice, 1,500 miles in length by 500 in greatest width and with an estimated area of 400,000 square miles. Much of it is between one and two miles above the sea and back from the coast all rock relief is hidden beneath the glacier plain. The scenery of glacial America was the same—an apparently unending plain of snow and ice, unmarked, except about its borders and there only in hilly country, by any rock masses. The chief difference was in size, for the continental glacier covered 4,000,000 square miles, ten times larger than the Greenland glacier of today.

Figure 18 shows the drift deposits of two of the later ice sheets, the Illinoian and Wisconsin, as they occur in Ohio. From Holmes County south and west, the last or Wisconsin glacier did not advance as far as the earlier Illinoian glacier, so that a belt of Illinoian drift lies outside the area of the Wisconsin drift. The occurrence of Illinoian drift to the southeast of Delaware County, beyond the border of the Wisconsin, shows that both glaciers passed over the county. But no


GEOLOGIC MAP
OF
DELAWARE COUNTY
SURFACE DEPOSITS
SCALE OF MILES
1 ½ 0 1 2 3 4 5 6
LEGEND
Valley Alluvium
Gravel terraces in Valley Alluvium.
Valley Alluvium veneering rock terraces.
Eskers
Kame-eskers
Gravels, in part kames, made during the ice retreat.
Ground moraine
Recessional terminal moraine
Glacial scratches
MARION CO.
MORROW CO.
MORROW CO.
UNION CO.
UNION CO.
KNOX CO.
LICKING CO.
FRANKLIN CO
THOMPSON
MARLBORO
OXFORD
RADNOR
TROY
BROADWAY MORAINE
MORAINE
SCIOTO
DELAWARE
BROWN
KINGSTON
PORTER
BERLIN
BERKSHIRE
TRENTON
CONCORD
LIBERTY
ORANGE
GENOA
HARLEM
POWELL MORAINE
MORAINE
Norton
Ashley
Radnor
Leonardsburg
Warrensburg
Delaware
White Sulphur
Klondike
Ostrander
Bellepoint
Stratford
Cheshire
Olive Green
Sunbury
Condit
Galena
Hyattville
Lewis Center
Powell
Harlem
Fulton Creek
Bokes Creek
Blues Cr.
Mill Creek
Whetstone Creek
Horseshoe Run
Delaware Run
Mill Run
Alum Creek
Walnut Cr.
Little Walnut
Long Run
Sugar Cr.
Culver Creek
Perfect Creek
Rattlesnake C.
Duncan Run
Eversole Run
Deep Run
Bartholomew Run
Slate Run
Olentangy River
Scioto
Hocking Valley
Hocking Valley System
Penna System
Pennsylvania System
N.Y.C.
C.C.C. & St. L.
C.D. & M.
Alum Creek

rests on unweathered bed-rock shows that all pre-glacial soil and all loose and rotten rock such as is usually found above the bed-rock was carried away. If we may estimate the amount of the soil and rotten rock removed by their thickness in the unglaciated limestone regions just beyond the extreme limit of the ice advance, it may have been between 10 and 20 feet. Below this weathered zone the glacier cut down into live, unweathered rock, though how much fresh rock was removed it is impossible to say, possibly not more than a few feet.

The material removed from any one locality was dropped along the course of the glacier between that place and the extreme margin of the ice, and some of it was carried by streams issuing from the ice to indefinite distances down the valleys leading to the Ohio. Some of the finest material lies today beneath the waters of the Gulf of Mexico. As compensation for the material removed from any particular area there is the present drift brought to that locality from points north.

Glaciated Surfaces

The bed-rock in the western half of the county is limestone and its surface beneath the drift is often unweathered, planed, smoothed, and scratched or striated with parallel or sub-parallel lines. The flatness of these surfaces is determined by the horizontal bedding planes of the rock; it is not a result of glacial erosion independent of previous rock structure. The smoothing and polishing came from the rubbing of these bedding-plane surfaces by the clay carried beneath the ice. The scratches or striae are due to the stones in the clay. Polishing and scratching went on together; the result of rubbing the limestone with the stony clay is not unlike what one would get by attempting to polish silver with a polishing powder containing some grains of sand.

Well-preserved glaciated surfaces are seen only in a few places, and best on limestone, usually where stripping in advance of quarrying has uncovered them. Excellent exposures have been seen at the quarry of the Scioto Lime and Stone Company and at Meredith's quarry near Radnor. No glaciated surfaces have been seen on the shales of the eastern part of the county; the shale is probably too soft to take and retain such effects. One small glaciated surface on the Berea sandstone was seen in a roadside gully southeast of Sunbury.

The striae show the direction of ice movement. So far as they are known they are shown on the surface geology map (Map II). At Meredith's quarry near Radnor two sets of parallel striae show, one N. 20° W., the other N. 2° W. The two crossing sets prove a shift in ice motion at this place and the N. 2° W. set seems to be the last formed. After the shift in direction, any further glacial erosion was not sufficient to remove earlier scratches.

When the striae are mapped for a large area the general direction of the ice movement can be seen (Fig. 18). In Ohio this general direction was southward. It has been pointed out that south of the St. Lawrence-Ohio divide the ice ran forward in each of the larger, south-trending valleys so that the border portion of the glacier was lobed; in each of these lobes the ice spread out fanwise toward the margin of the lobe. Delaware County is centrally located in the Scioto lobe; in its western part the striae are a little east of south, in its eastern part, if the Sunbury exposure is typical, more southeasterly. Further, during the advance and the retreat of the ice lobes the direction at any particular point varied as that point varied in its position relative to the margin of the lobe. This, quite as well as shifting currents within the lobe while the margin was stationary, may explain crossed striae, like those at Meredith's quarry.

Our present knowledge of glacial geology, as of all other divisions of geology, is a slow acquisition through the past decades. It is therefore of interest to compare an earlier view of the glacial geology of Ohio (Geological Survey of Ohio, Report of Progress in 1869, by J. S. Newberry, pp. 24–31), with that in the present report, or in any current report covering Ohio geology. Newberry's report, written in 1870, fifty-six years ago, was fully abreast of his time. He recognized glaciers in North America, but they were valley glaciers, "flowing by various routes to the sea," one of which "flowed from Lake Huron, along the channel now filled with drift * * * into Lake Erie * * * following the line of the major axis of Lake Erie to near its eastern extremity; here turning northeast the glacier passed through some channel on the Canadian side, now filled up, into Lake Ontario, and thence found its way to the sea, either by the St. Lawrence or by the Mohawk and Hudson." (p. 27). That the glacier flow was parallel to the axes of Lakes Huron, Erie, and Ontario is brought out in the map (Fig. 17), but it was the flow of south-trending lobes of a continental ice sheet covering the whole region.

The till or boulder-clay is recognized, but is mistakenly identified with certain laminated post-glacial clays (Champlain clays) of the Champlain and Hudson valleys. It is regarded as a water-lain deposit at a time "when the continent was depressed five hundred feet or more below its present level; when the climate was much warmer than before, when the glaciers retreated northward and were gradually replaced in the region of the great lakes by an inland sea of fresh water." (p. 28). The sands, gravels, and boulders associated with the clays were "*floated* to their resting places, and that by icebergs. * * * When our lake-basin glaciers had retreated to the highlands north of the lakes, icebergs were detached from them, and floated southward, sowing sand, gravel, and boulders broadcast over the southern shallows, just as they are now doing over the banks of Newfoundland and the bottom of the Antarctic ocean." (p. 28). Later studies have shown us that these boulder-clays are the direct deposit of the ice-sheet, and that the sands and gravels interbedded in them were deposited by waters at the front of or under the ice.

Studies in the history of any science show us that the present body of scientific knowledge is the slow accumulation of many past workers; and that as at each stage our knowledge has been incomplete and in part erroneous, so it must in all probability be today.

Direct Ice Deposition

The boulder-clay or till.—The character of the deposits left by the glacier can be seen in the banks of many streams throughout the county and is well shown in the cuts at the two clay works in East Delaware, and in the large openings east of Delaware where the Pennsylvania Railroad got its material for the railway embankment past Delaware. The till or boulder-clay, as the second term indicates, consists of two parts, a clay base or matrix, which makes perhaps 95 per cent of the whole deposit, and the embedded stones or boulders.

The clay

The clay is compact, fine-grained, yellowish-brown in color, and on drying breaks into small angular pieces. Samples taken from any level below the upper three or four feet effervesce in acid, showing the presence of calcium carbonate derived from the mechanical wear of limestone. In the upper three or four feet this finely divided limestone has been removed by the leaching action of descending soil water and in the upper two feet even the limestone pebbles have been dissolved out.

The carbonate of lime in the clay is a proof that the till consists in part of limestone mechanically ground up beneath the glacier (limestone rock-flour); it is equally clear, on consideration, that pre-glacial soils brought from the north by the advancing ice must enter into the make-up of the clay. There is no way of determining the relative proportions of these two constituents.

The clay, as noted above, is commonly yellow-brown in color. Where it is unusually thick, particularly if very compact and nearly impermeable to water, the color of the lower part may be blue or ash-gray. This last is the original color; the yellow color nearer the surface, which is the only color showing at most localities, is due to the oxidation of the ferrous compounds of the clay to limonite by downward percolating waters. The oxidation of the iron compounds goes to a much greater depth than the leaching of the lime carbonate, to from 10 to 20 feet or more below the surface and commonly through the entire thickness of the drift.

Streaks or seams of sand are often found; in some localities, up in the clay, at others, lying between the clay and the bed-rock. In the Pennsylvania Railroad cut, east of Delaware, mentioned above, a layer of gravel some six feet thick lies at the base of the till and can be traced for several hundred feet. It represents a gravel deposit made in front of the advancing glacier, later overridden and buried beneath the till. It is only from such sand or gravel layers in the till that any dug wells in the till can get water.

The boulders

The stones in the boulder-clay vary in size from small pieces to large blocks several feet in diameter. The largest block seen is three-quarters of a mile south of Stratford on the river flat west of the Olentangy River and is 12 x 8 x 4 feet in size. Plate XA.

The boulders often show the typical features of ice-worn blocks; they are sub-angular, i. e. angular with the corners and edges rounded off, their sides planed, smoothed, and scratched. Many of the limestone blocks have been roughened by solution and so lost their original glaciated appearance. The worn character of the boulders proves that they were carried under the ice. The general absence of the boulders over the surface also points to sub-glacial carriage; had they been carried up in or on top of the ice, they would have been let down, on the melting of the glacier, and deposited on top of the drift. They are rare over the general upland till surface and are generally found on the surface of the ground only in valleys where they have been washed out from the clay and left behind as an incident in the erosion of the valleys.

The boulders though conspicuous make up but a small per cent of the boulder-clay. In the clay cuts in East Delaware the boulders are thrown aside and left over the floor of the cut. Estimates here of the proportion of the boulders in the original till vary from two to five per cent.

Many of the stones in the till are of local origin. East of the Olentangy, at Delaware, the bed-rock is Ohio shale. On account of its crumbling character large blocks of the shale do not occur in the till but abundant fragments of the shale make their appearance as soon as the shale outcrop is reached on going east. This shale material is of immediate local origin. Occasional boulders of dark limestone from the Ohio shale concretions are found in the drift near the west edge of the shale outcrop, which have certainly not moved more than one or two hundred feet from their original position. The limestone boulders, from various counts, make up 80 to 90 per cent by number of the boulders of the till and many of these are from the Columbus and Delaware limestone belts in the central and western part of the county, and so cannot have traveled more than a few miles. Other limestone blocks may have come from places as far north as Lake Erie or even southern Ontario. The larger boulders are almost invariably of crystalline rock, granite, gneiss, schist, greenstone, anorthosite, and coarsely crystalline marble, which cannot have come from a locality less distant than the pre-Cambrian area of Ontario, a distance along the course taken by the ice of at least 450 miles. Frequent boulders of hard, quartzitic sandstone come from the upper Cambrian outcrop which follows the south border of this pre-Cambrian area. These quartzitic sandstone and crystalline rocks make up less than ten per cent by count of boulders in the drift.

West of the Olentangy River the till rests on firm limestone bedrock. East of the river, where it rests on the Ohio shale, there is usually

A.—Glacial boulder near Stratford. Size 12 x 8 x 4 feet. Its original home was north of Lake Ontario.

B.—Coarse gravel along the Scioto, showing that the river formerly had large transporting power. Boulders reach two feet.

a layer of broken shale, up to four feet in thickness, between the undisturbed Ohio shale and the till. This broken layer does not properly belong with the till, as it contains little if any admixture of foreign material. Nor is it strictly bed-rock; rather it results from the mashing of the upper part of the Ohio shale by the drag of the glacier.

Surface Form of the Glacial Drift

The till plain.—Throughout most of Delaware County the till surface is a nearly level plain. This is best shown over the inter-stream areas, particularly west of the Scioto, north of Warrensburg; between the Scioto and Olentangy south of the Springfield Branch of the Big Four Railroad; north from Radnor; and east of Delaware. Indeed all parts of the county which are not cut by valleys and are not within the terminal moraine belts described below are level till plain. Large areas are almost perfectly flat and must be tiled to make good farming land. Through much of the county it is impossible to fix the divide between the main south-flowing rivers. This till plain, which is the most characteristic feature of the scenery of the county, extends far to the north and west, so that Delaware County shares its rather monotonous landscape with a large section of the State.

The bed-rock surface beneath the till plain is slightly more uneven than the present till plain surface. Glacial deposition made for greater flatness. The effect is comparable with a coating of plaster over an uneven brick or masonry surface, which conceals the minor, though not the larger, irregularities and gives a more nearly plane surface.

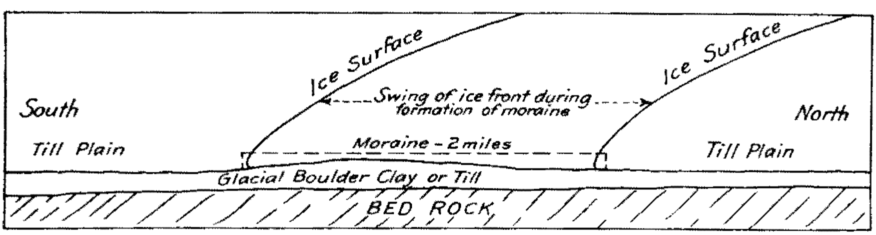


Fig. 19. Diagram showing formation of moraines.

The moraines.—Two belts of higher and more rolling land, terminal moraines of thicker drift accumulation, stand in more or less contrast with the nearly level surface of the till plain. The southern or Powell moraine follows the south border of the county across Concord and Liberty townships to the Olentangy River, whence it takes a northeast course to Galena on the Big Walnut, the west bank of which it follows to the northern line of the county. North of Sunbury the moraine lies along the outcrop of the Berea sandstone. The northern or Broadway moraine enters the county near Ostrander, swings around to the north, and about three miles northwest of Delaware turns again to a more easterly course which it holds to the county line. See Map II.

The moraine belts vary in width from less than one to two and one-half miles. They rise rather sharply from the level till plain to the south to a maximum height of 50 to 60 feet. West of the Scioto this maximum is reached for both moraines; eastward the moraine crest is lower, 30 to 40 feet or even less above the plain to the south. The crest of the moraine is usually nearer its south edge; from this crest the surface of the moraine drops away more gently to the till plain on the north, with which it merges. These belts of thicker drift represent a stage during the melting of the glacier, when the ice front instead of moving back at a uniform rate and so depositing an approximately uniform thickness of till, either stood still or more likely for a time alternately advanced and retreated across a narrow belt. As the ice itself was at all times moving southward and dragging debris with it there resulted a belt of thicker drift. This is a terminal moraine, since it was formed at the margin of the glacier; and a recessional terminal moraine, as it was formed during the recession of the ice front. Ten such recessional moraines are found along the axis of the Scioto lobe of the Wisconsin glacier south of Lake Erie, of which two cross Delaware County. Figure 18 shows the relations of ice, moraine, till plain, and bed-rock. The ice front did not remain fixed but swung between the two extreme positions A and B. The figure shows why the crest of the moraine is nearer to the south edge and why the northern slope, overridden by the glacier, blends with the till plain on the north.

The surface of the moraine is usually rolling. South of its crest this is in part due to valley cutting by temporary streams discharging at the ice margin at the time the moraine was forming. But in large part these irregular rolls are due to the inequalities of direct deposit by the ice, and this is clearly true when shallow basins without outlet occur on the moraine. Farther north, in Wisconsin and Michigan, where the moraines are higher and more hummocky, the hollows are more pronounced and often contain lakes; the moraines are then often called kettle moraines. The recessional moraines of central Ohio are in comparison subdued and rarely contain lakes. In places even the low rolls common in the moraines of the central part of the State are lacking and the moraine becomes a simple swell above the till plain.

Mapping the terminal moraines presents several difficulties. While the moraines are distinguished from the till plain by their greater height and more rolling surface, the surface of the till plain itself is often gently rolling and in places the moraines stand but a few feet above the adjacent plain. On its north side the moraine passes so gradually into the till plain that the northern boundary is in places arbitrarily drawn on the map. Where the ice margin lay across one of the main drainage lines the swollen stream prevented the accumulation of a moraine in the bottom and on the lower slopes of the valley. Further the main valley slopes are cut by small side streams so that as one follows the moraine toward the valley the characteristic moraine topography becomes confused with rolling stream-shaped topography. The mapping of the back edge of the moraine and of the moraine where it crosses the river is therefore somewhat arbitrary. The front edge of the moraines on the interstream uplands is generally though not always well defined.

Streams are sometimes used as aids in mapping the moraine. They often flow for longer or shorter distances in the low area at the front margin of the moraine and sometimes seem to have taken a course along the back edge of the moraine between it and the ice front immediately north. See page 105 for discussion of moraine control of streams. When, then, the streams follow courses which fall in with the general line of the front or back margin of the moraine, even if there is no marked topographic contrast on the two sides of the stream course, the stream course has often been taken as the moraine boundary. This has been done on the two sides of the Broadway moraine near the east side of the county, and beyond in Morrow County for at least six miles Turkey Run appears to mark the back and Alum Creek the front edge of the moraine, which itself is not topographically well defined.

Patches of terminal moraine are shown on the map, almost all of them east of Big Walnut Creek, which do not belong to either of the two main belts and which cannot be aligned to make minor belts parallel to the main belts. They are areas of somewhat higher and more rolling drift than the surrounding plain. Some of these might as well have been omitted in the mapping and other similar areas not shown might equally as well have been inserted. The till plain itself is often rolling and it is a question of judgment when it rolls enough to be considered moraine. In geology as with people one can sometimes tell a thing by the company it keeps: when such areas are associated with one of the main belts, they have been mapped; when out of alignment, they have often been omitted. The line of isolated patches which runs north, from east of Westerville, probably has significance as marking a minor stop of the margin: the patches east of Big Walnut Creek in Trenton and Genoa townships have little significance.

Aqueo-glacial Deposits

Period of increased stream flow.—The retreat of the ice margin from the southern border of the county to a position north of the Lake Erie-Ohio divide in northern Marion County required but a short time geologically[1], a time which cannot be given at all closely in years but which may have been several centuries compared with the few tens of

[1]See note p. 135.

thousands of years which many geologists believe have elapsed since the maximum of the Wisconsin ice.

But the work done by streams during this relatively short period was great for two reasons: first, the flow of all the larger streams crossing the county was very much greater than today because they were carrying off not only the local precipitation which was not less than that of today, but a great amount of water from the melting glacier, a part of the precipitation of northern Ohio and central Canada, which today would go to the sea by the St. Lawrence, but which was then being brought in solid form as ice south of the St. Lawrence-Ohio divide and added to the flow of our local streams. It is not possible to say how many times greater the flow of our rivers was at that time than at present; that it was much greater is shown by the coarseness of the gravels they carried and by the amount of valley cutting they did during this relatively short period.

A second factor favored large stream work during this time. Great quantities of stony clay, sand, and gravel were being dumped at the edge of the ice, and the land surface from which the glacier had recently withdrawn must have been bare of vegetation for some distance south from the ice margin. If, as is likely, the ice margin oscillated during the northward retreat, the frequent readvances destroyed any beginning vegetation immediately in front of the glacier. Both the greater amount of loose debris and its easy accessibility to stream carriage because of the lack of a protecting cover of vegetation help to explain the overloaded character and large deposition by the waters flowing from the ice margin.

Glacial drainage lines.—The valleys of the Scioto and Olentangy are in large part determined by the location of north-south belts of softer rock and were in existence before the last or Wisconsin glacial invasion; the same is probably true for parts of the valleys of Alum and Big Walnut creeks. These pre-Wisconsin valleys were modified but not obliterated by the erosion and deposition of the Wisconsin ice, and as the glacier retreated northward they became the lines along which the main discharge of the flooded glacial waters took place. The overloaded streams from the ice front floored the valleys with thick deposits of sand and gravel, the gravels often coarse, in some places containing boulders to between one and two feet in diameter. Plate X B shows these large boulders on the east side of the Scioto, three miles north of Warrensburg, in a pit from which gravel was dug for the old Magnetic Springs trolley line. Bownocker[1] has pointed out that at Columbus sand and gravel dredged from the bed of the Scioto is replaced by the river with mud, and this may have a bearing on the early greater transporting power of the rivers.

[1]Geol. Survey of Ohio, Bull. 14, p. 120.

The work of glacial waters was greater along the Olentangy and Scioto than along the valleys in the eastern part of the county, and for two reasons: first, as the ice withdrew in a northwest direction the eastern drainage areas were earlier abandoned by the ice, and second, the greater expansion of the upper valley of the Scioto north beyond the limits of Delaware County favored excessive run-off in that valley during the final withdrawal to the Erie-Ohio divide.

The conditions at the time when the ice margin was at the Broadway moraine northwest of Delaware are easily pictured. At that time the ice front had withdrawn from the drainage basin of Big Walnut Creek. A certain excess discharge followed the front of the moraine to Kilbourne and thence south along Alum Creek Valley. But the main discharge was along the valleys of the Olentangy and Scioto. For a short time a third line of main discharge was Delaware Run. The map (II) shows a north pointing re-entrant in the moraine front, northwest of Delaware. This re-entrant is determined by a rise in the bed-rock surface which can be traced from north of Radnor south nearly to White Sulphur. This ridge, while but little higher than the limestone floor to the east, stands on the average fifty feet above the bed-rock surface west along the Scioto. As the ice, moving southeastward, crossed this ridge, its margin hung back on the ridge and the re-entrant was made. That the waters, concentrated at this point of the ice front, followed the valley of Delaware Run in considerable volume is shown by the fact that the valley of the run is much larger than the present volume of its stream demands (where it is crossed by the Hocking Valley Railway the valley of the run is as wide as that of the Olentangy), and by the extreme coarseness of the gravels along the run through the city of Delaware.

The rock level of the valleys varied down stream and the gravels in consequence vary in thickness. On the higher portions of the rock floor they may be a few feet in thickness, while at a place up valley where the rock floor is lower they may be several score feet thick. Subsequent down-cutting by the rivers has left these deposits as terrace fragments well above the present stream levels. The Scioto of the time was flowing at the south border of the county 50 feet above the present river. Where Alum Creek enters the county, the glacial channel was 40 feet above the present stream and the old gravel floor is represented today by a series of remnants on a rock platform which can be followed on both sides of the stream to below Kilbourne.

Minor spillways.—In addition to the discharge to the main valleys, smaller streams, yet often of good size, must have issued from the ice front at many places. These streams cut broad valleys which ultimately opened into one or another of the main valleys. As the ice margin withdrew northward such valleys would be extended northward as new ground was uncovered, so that they generally have today north-south courses. With the final disappearance of the ice and the cessation of extra water supply the valley would be without a stream, unless of sufficient size to possess one of its own. Many such open valleys are found today without any streams and many of the smaller streams occupy such valleys, which they evidently have not themselves cut, but which were prepared for them by the temporary ice front drainage. This mode of valley origin largely accounts for the numerous open south-trending valleys, found particularly in the northern and eastern parts of the county.

The Radnor Esker and Kame System

Eskers.—A double line of interrupted gravel and sand ridges (eskers) starts in Marion County just south of Prospect and continues south-southeast to beyond Radnor (see Map II). The western line lies from a half-mile to a mile east of the Scioto. About a mile and a half south of Prospect it stops, but is resumed two miles farther on and continues to southwest of Radnor where it passes into a series of broader gravel ridges which end against the Broadway moraine. In places this western line is double and twice the ridges fork. The longest single ridge is a half-mile in length but close-trailing ridges west of Radnor reach a length of more than a mile. The ridges are not high; a cross section of one of typical shape and size near the south end gave a width of 150 feet, a height of 20 feet. Plate XI A shows one of medium height. When cultivated, as they often are, with the rest of the field of which they are a part, they are in places covered with limestone gravel.

The eastern line of eskers lies near the Prospect-Radnor road. The knolls here are wider and higher, reaching a maximum height of 40 feet above the plain.

In addition to the two main lines, occasional isolated gravel knolls occur, with their longer axes in the general direction of the esker system. They are shown on the map.

Kames.—To the south both lines of eskers widen to gravel belts, in places a quarter of a mile wide, but which still retain their southeast trend. Still farther south these broader belts pass into and merge with broad rolling hills without distinct southeast trend, which lie against the north slope of the Broadway moraine. These last are kames. They cannot be told from rolling morainal hills from their surface form; their kame character is known only when their gravelly make-up is known.

The wide elongated ridges which connect the eskers farther north with the kames are an intermediate type which can be called kame-eskers.

Composition.—Frequent openings in the esker ridges and kames for road material show sand and gravel. In the ridge at the south end

A.—Esker near Radnor. Eskers are not very common in Ohio and this is one of the best in the State.

B.—Section of esker. The stratification proves that it is a water and not an ice deposit. Moreover the cross-bedding indicates that the deposits were made by shifting currents. The coarser material is at the top of the section.

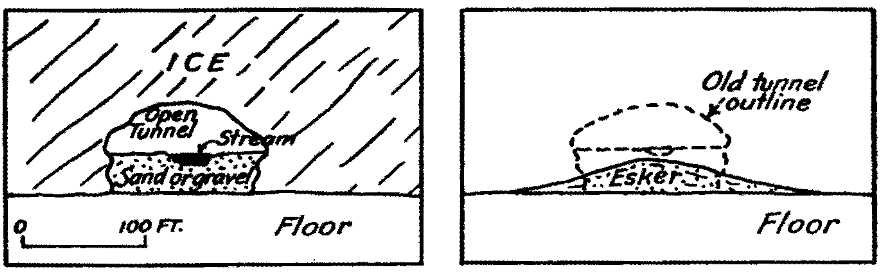
of the village of Prospect the material is coarse gravel, many pieces over a foot in size, laid down, as shown by the northward inclination of the flat limestone blocks, by a south-flowing stream. Fine sand lies in the bottom of this cut but it no longer shows. In an opening a half-mile farther south, on the west side of the road, beautifully cross-bedded sand is shown, capped by gravel (Plate XI B). The vertical order of the size of material is wholly determined by the velocity of the depositing stream at different stages of construction. More often than not the coarser material is at the top; probably because it took a stronger current to drive the waters to the higher levels.

In a cut in the esker just north of the school house at Radnor several feet of till overlies the gravel, as if a slight advance of the ice had taken place after the formation of the esker.

Origin.—The sand and gravelly composition of both the eskers and kames shows that they are deposits from running water.

The kames are believed to be the deposits of streams emerging at the ice front and dropping the main part of their load at the ice front. Probably this was favored by the rising slope of the Broadway moraine to the south.

The esker ridges clearly have a somewhat different origin. They stand well above the surrounding plain yet their form shows that they



Figs. 20, 21. Formation of esker in ice tunnel (on left) and section of esker (on right).

are not residuals left from the stream dissection of a general gravel deposit. They were made by streams flowing in tunnels within or beneath the ice. Figure 20 is a cross section of such a tunnel showing the confining walls of ice and the flat of sand and gravel built therein by the stream. Figure 21 shows the same after the ice has melted and the deposit, the original outline of which is shown by dotted lines, has by slumping taken the convex form which is the typical cross section of the esker.

With this method of origin in mind, it is easy to explain the interruptions in the esker system as shown on the map. If for any reason the ice tunnel narrows, the stream's velocity would be increased and deposition might not take place. With the disappearance of the ice there would be at that place a break in the continuity of the esker.

This is quite like the failure of an ordinary stream to deposit in the narrower parts of its course where the current is swifter. The lines of parallel eskers and occasional branching of the esker ridges means either that the sub-ice drainage was along several roughly parallel channels or that it shifted its position from time to time, as channels within the ice opened or closed.

The explanation of the broad gravel belts with distinct southeast trend is suggested by Figure 22. The position of the ice margin is shown at AB. A sub-glacial stream in a tunnel is shown at EFGH; this may be

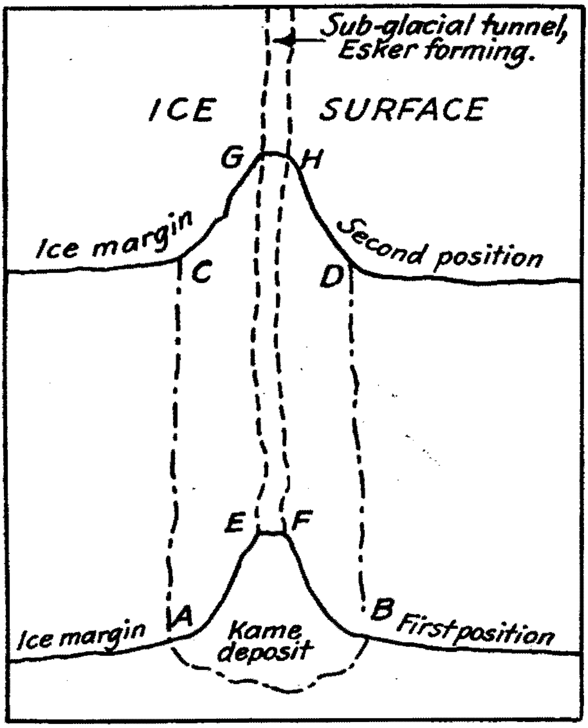


Fig. 22. Formation of kame and esker.

considered engaged in esker formation. At the point of exit of this sub-glacial stream, EF, the ice front would be likely to melt back into a triangular re-entrant as shown in the figure. Here the emerging stream would deposit sand and gravel kames, banked up against walls of ice on either side, but exposed to the light of day. If now the ice were to retreat to the position CD, this broader deposit would be extended northward and a broad ridge produced, ACDB, with trend parallel to that of the esker system as a whole, but quite too wide to be regarded as an ice tunnel product. In position it would connect up the typical esker to the north with the kames.

As the ice melted back from the north side of the Broadway moraine the course of the overloaded ice-margin streams was along the back of the moraine a little west of south to the Scioto River, at a point opposite Bokes Creek, along the line of gravel deposits shown on the map (II). When the ice front had retreated still farther and lay across the Scioto in a north-northeast direction a little below Prospect, the escaping drainage made extensive gravel deposits in front of the ice which are now found in a belt over a mile in width for five miles south of Prospect on the east side of the Scioto.

Two reasons may be assigned for the location of the Radnor esker system. It is on the north side of the Broadway moraine and this rising slope to the south may have had a share in blocking the drainage and causing deposit. But this is probably of slight influence. If it were a determining factor we would expect similar deposits more generally along the north side of the recessional moraines.

Much more significant is the location of the system against the north-pointing angle of the Broadway moraine. As already suggested (p. 95), this angle is determined by the lag of the ice front where it crosses the north-south limestone ridge southwest of Radnor. The surface of the ice against the re-entrant was probably lower than to east or west, resulting in a concentration of the waters from surface melting along the line of the present esker system. The movement of the ice across the rock ridge would have resulted in fissuring the ice and diverting a large share of the drainage to sub-ice courses. The combination of conditions is believed to be responsible for the location of the esker system in this part of the county.

Other kame deposits

At several localities on the Olentangy River gravel hills or kames are found on the uplands immediately bordering the valley. Deposits of this kind are found on either side of West Branch where it joins the main stream and at several points north of Waldo, on the east side of the Olentangy.

In the east part of the county, in Trenton Township between Perfect and Rattlesnake creeks, are a number of conspicuous gravel hills, some rising sharply from the plain to heights of 50 feet or more. They are easily distinguished from morainal knolls both by their steepness and by being composed of sand and gravel. They are kames, formed at the front of the ice. They do not, however, connect up with any moraine or esker system.

CHAPTER IV

STREAM WORK IN POST-GLACIAL TIME

Consequent and Subsequent Drainage

When a land surface is exposed for the first time to rainfall, as when a sea bottom is raised above sea level or an ice sheet disappears by melting, the run-off follows the lowest parts of the new surface. Its course is solely a consequence of the initial surface inequalities. Such drainage is called *consequent.*

With the passage of time these streams lengthen by headwater gullying and side tributaries develop by the same process. Such later additions make the *subsequent* drainage. At the start the subsequent drainage is *nil*; with time it makes an ever increasing part of the total drainage of the region.

The drainage of Delaware County is almost wholly consequent, developed on a new surface left by the melting of the ice sheet; a drainage controlled by a thin veneer of glacial drift over a bed-rock surface. To understand it, it is necessary to know the main features of the bed-rock surface and of its glacial cover.

The bed-rock surface.—The bed-rock surface of Delaware County is in a large way a plain, rising from about 950 feet in the central part to 1,100 feet along the Scioto-Licking divide on the eastern border. It is in part flat and even where one approaches the higher land of the eastern border it is still a plain that one sees.

The rocks however dip to the east at an average rate of 25 feet per mile. The surface of the plain then cuts across all the rock formations from the Monroe to the Cuyahoga, a series about 1,050 feet thick. The only known way in which a plain can be developed across inclined beds in the humid interior of the continent is by continued stream erosion producing a plain at the lowest level to which streams can cut their valleys, which would be not far above sea level. Such a plain is a *peneplain.* As this Delaware County peneplain now averages something over 1,000 feet above sea level and is being trenched by streams, it must have come up to its present position through earth uplift amounting to several hundred, perhaps 800 or 900, feet. This peneplain is believed to be the extension into central Ohio of the peneplain of southwestern Ohio, represented by the level uplands about Cincinnati standing now 1,000 feet above sea level. In central and northern Ohio it may have been modified by glaciation and earth tilting.

This peneplain in the county is gently rolling, not flat. The rock formations are in north-south belts and are of unequal hardness, the harder belts giving strips of higher country not completely reduced to the peneplain level. One such rise occurs along the outcrop of the Berea sandstone; a second along the contact of the Ohio shale with the very soft underlying Olentangy shale. Possibly the high strip southwest from Radnor is due to a harder part of the limestone.

Glacial till plain.—Over the slightly uneven surface of the peneplain, the glacier laid its deposit of boulder-clay, varying from almost nothing to thirty to forty feet in thickness. Locally, as for example along the course of the Powell and Broadway moraines, the unevennesses of the drift made the present surface more uneven than the pre-glacial surface. Over the county as a whole, however, the effect of the veneer of glacial deposits was to give a flatter surface to the county than it had previously had; much as mortar conceals the roughness of a stone or brick surface. The present level surface of the county is then a glacial plain, superimposed on an earlier peneplain, and it was on this surface that the consequent post-glacial drainage took its course.

Pre-glacial valley trenches.—An inspection of the topographic sheets shows that in the central and southern parts of the county the Scioto and Olentangy rivers, and in part Alum Creek flow in an inner valley cut in the bottom of a wider and deeper outer valley or trench. The general uplands stand at 940-950 feet, are nearly flat, and 100-150 feet above the rivers. At from three-quarters of a mile to a mile back from the stream the slopes to the rivers begin; this is the border of the trench. The trench is cut in rock and veneered with till; hence it was in existence previous to the Wisconsin glacier. Whether previous to the earlier glacier is unknown.

The explanation of the trenches involves several considerations. In general they follow the strike of the rock formations and may have been located by belts of softer rock. This is most probable for the Olentangy trench, which roughly follows the soft Olentangy shale belt. Then, too, glacial striae show that the ice moved parallel to the Scioto trench, and the same was doubtless true for the nearly parallel Olentangy trench, though striae are not preserved on the shale. It is probable that ice following the preglacial valleys altered and enlarged them and so is responsible for the final form of the trench.

As the ice withdrew northward the till-veneered plain came into view, sloping gently southward toward the Ohio and marked by certain trenches and rises which in general corresponded to the north-south strike of the bed-rock. On this plain the four main streams took nearly north-south courses. The Olentangy and Scioto resumed their courses in their respective trenches in the southern and middle parts of the county. North of that they followed the retreating ice front with less marked topographic control. A similar explanation holds for Alum

Creek, with trench control playing a less important part. Big Walnut Creek is without trench control. It follows the front of the Broadway moraine from Morrow County to Galena, from there south it follows the lowland west of the Berea rise.

Other buried valleys.—Sharply cut valleys now filled by drift and concealed, except when the later drainage has crossed their course, have been found at several places in Franklin County. Along the lower sections of some of the larger valleys in Delaware County, rock walls locally give place to walls of drift which may be either buried parts of the main valley or pre-glacial valleys crossed by the modern valleys. It has not been possible to trace such valleys back from the main valleys and so determine any pre-glacial drainage system different from that of today.

The Main Streams

Introductory.—When one of the main streams took its course in the drift-lined pre-glacial trench, it did not everywhere follow the axis of the earlier valley. In places it came upon bed-rock to one side of the deepest part of the trench and at less depth. At these places the first torrential stream, instead of cutting immediately into bed-rock, may have been held for a time at the rock surface level, especially if that were limestone, and stripped the drift cover somewhat widely. Later, on cutting into the bed-rock, its valley would be narrower and the earlier rock surface would be left as a rock terrace veneered with alluvium. Upstream from such a rock barrier, where the stream was on the glacial drift, the drift may have been reworked to a considerable depth below the level of the rock barrier down valley and gravel deposits laid down, determined in upward level by that of the rock barrier next down valley. Later when the stream deepened its valley the terraces here would be gravel terraces. Such gravel terraces and rock terraces veneered with gravel are frequent along the Scioto and Olentangy rivers.

The Scioto.—The Scioto from the Marion County line to Bokes Creek flows largely on drift, though occasional outcrops of Monroe show it is not far above bed-rock. It lies but little below the general level, with a fall of about $2\frac{1}{3}$ feet per mile. South from Bokes Creek the river is in its pre-glacial trench, usually on rock, and has a slope to the Franklin County line of 8 feet per mile. For three miles north of the Franklin County line alluvial-veneered, rock terraces are found on the east side of the river, and similar features are found south in Franklin County between Dublin and the broad section of the Scioto Valley at Columbus, where the valley is out of bed-rock and in drift. West of Powell this rock terrace is 850 feet above tide and 60 feet above the stream level; below the Columbus storage dam, 800 feet above tide and 80 feet above stream level. In this part of its course the Scioto is flowing in a rocky valley, with an average width of 1,000 feet, cut 60 to 80 feet below the earlier valley level, which is in places a half mile or more in width.

The Olentangy.—The Olentangy, from Marion County to where the Pennsylvania Railroad crosses it three miles north of Delaware, is flowing in a flat-bottomed valley cut 20 to 40 feet below the generally flat till upland. In the northern part of this section it is in drift; in the south, Ohio shale makes cliffs at several places in the east bank. The fall is slight, about $4\frac{2}{3}$ feet per mile. South from this to the Franklin County line it is in its pre-glacial trench, with an average drop of 8 feet to the mile. The valley is largely influenced by its relation to bed-rock. A mile south of Delaware the river passes from the shales to limestone and continues on limestone almost to the county line. North of Delaware

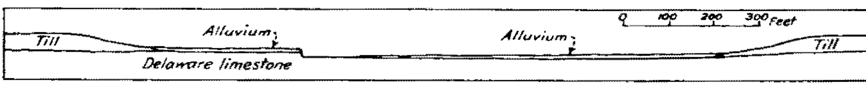


Fig. 23. Cross-profile Olentangy Valley one mile below Delaware.

it follows approximately the outcrop of the Olentangy shale, a soft formation lying above the hard Delaware limestone and below the somewhat harder Ohio shale. The beds dip to the east. In cutting into the rocks the river has cut down into the Olentangy and then in its lateral swinging has cut eastward down the dip. This is especially marked in parts, as at Delaware, where it has cut to the top of the limestone and then has worked eastward down the dip surface of the limestone. The marked river bends which are shown on the Delaware sheet are all at places where the river is flowing on the Olentangy shale and undercutting its east bank, with the Olentangy at the base of the cliff. South of Delaware, on the limestone, the rock valley is narrower and conspicuous loops are absent.

Rock terraces, veneered with alluvium, are found at intervals along the limestone part of its course south of Delaware, though nowhere has the stream cut its valley more than about ten feet below the original surface of the rock. The rising limestone surface south of Delaware formed a dam for the river north and gravel terraces are here found to a height of 20 or more feet above the river.

Alum Creek.—Alum Creek follows the front of the Broadway moraine for two miles south of the Morrow County line, thence a nearly south course across Delaware County. From Cheshire south a rising slope for a half mile back from the edge of the valley suggests a preglacial trench, but the evidence is not decisive. On the Marengo sheet, north of Cheshire, the valley is in shale and narrow; south of Cheshire the valley is broader, probably because more largely in glacial drift.

Alum Creek has a nearly uniform drop of six feet per mile across the county. A rock terrace which marks an earlier bed can be traced, usually on both sides of the river, from Morrow County south through Kilbourne. At the county line it stands at 940 feet, 35 feet above river level. For a mile north and south through Kilbourne it makes a flat, one-half mile wide, on the west side of the river. Farther south no similar rock terraces are found, although the gravels in places rise to 20 feet above the river level.

Big Walnut Creek.—Big Walnut Creek follows the front edge of the Powell moraine from the county line south to Galena; from there its course is nearly south to Franklin County, in the shale belt a little west of the base of the topographic rise over the Berea sandstone belt. The average drop per mile in crossing the county is 13 feet, greater than any of the three other main streams. In its upper course it flows in a rather broad valley in the drift, with bed-rock exposures at rare intervals. Above Perfect Creek, Big Walnut enters a narrow valley in the Berea sandstone and continues in this narrow, rock-walled gorge until it runs onto the Bedford shale just south of Galena. In this section the drop is 25 feet per mile. South of Sunbury the valley is wide, the side slopes sometimes in shale, sometimes in glacial drift. Rock terraces are not seen along Big Walnut though gravel terraces rising to 20 feet or more are found at places, best shown south of Galena on the east side of the creek. A number of good sized tributaries enter the main creek, all, except Little Walnut Creek, from the east, a consequence of the rising slope eastward to the Scioto-Licking divide.

Minor Streams

General control.—The courses of all minor streams are consequent; they are determined by irregularities of the drift surface. The largest element of control exercised by the drift surface of the county is its southward slope, giving a general southward direction to the drainage. Streams with an east-west component of flow have more and larger tributaries entering them from the north than from the south. The tendency to southward courses was emphasized by the special conditions which held during the ice retreat. As the ice front withdrew northward across the county numerous streams issued from the ice front and started broad, shallow valleys which extended northward with the northward retreat of the ice front. These valleys are sometimes empty of drainage today, sometimes occupied by streams which are markedly undersized for the valley in which they flow. Delaware Run occupies a valley which is in its lower part as wide as that of the Olentangy, a valley not shaped by the present stream but by a much larger one which was in existence only during the time the ice front was retreating from Delaware to north of the Broadway moraine. Horseshoe Run occupies the lower part of a similar broad valley reaching south from

Marlboro church. Many examples on a smaller scale are found in the county.

The second largest surface control is the eastward rise of the surface in the eastern part of the county to the Scioto-Licking divide which lies just east of the county line; this is responsible for the eastward component of the courses of the streams entering Big Walnut Creek from the east.

Moraine control.—The influence of the recessional moraines on the direction of stream flow is marked. Big Walnut follows the front of the Powell moraine to below Galena. The north edge of this moraine is marked by a succession of small streams, from the Morrow County line to the Olentangy River. The Broadway moraine from Morrow County to the Olentangy River is followed on its south edge first by Alum Creek and then by the lower part of Horseshoe Run; on its north side by Turkey Run. In the intermoraine areas the streams often show parallelism to the general course of the two moraines which is best explained by their having taken a course along the ice front. Such streams, from Norton southeast, are: Whetstone Creek, Upper Horseshoe Run, Sugar Run above Greenwood Lake, Little Walnut Creek above Berkshire, and parts of several smaller unnamed streams.

Trench control.—A marked feature of the minor drainage is the series of close-spaced tributaries along the sides of the trenches of the main rivers in the southern half of the county, especially along the Olentangy and Scioto. The greater slope here is responsible for the numerous streams which are working back by headwater erosion into the inter-stream upland. They are responsible for the location of the railroads, which are on the upland, and far enough back from the Olentangy to avoid the deeper part of the many side streams. The old line of the Pennsylvania crosses the Olentangy at Delaware by dropping to the flat level south of the city, and climbing to the upland level again to the north. The new line of the Pennsylvania and the Springfield branch of the Big Four cross at the upland level on high bridges.

Stream-flow survey in Delaware County.—Two stream-flow measuring stations are maintained in the county by the State and Federal governments as part of their work of making a comprehensive survey of the water resources available in Ohio for all purposes. One station is on the Scioto River three-fourths mile below the O'Shaughnessy dam. The other is on the Olentangy River at the highway bridge four miles above Delaware. These stations were established in 1921. Both are equipped with automatic water-stage recorders housed in suitable concrete structures. An accurate and continuous record of the stage is thereby obtained. The river channels at the stations are investigated by taking sets of soundings and velocity readings at all stages from extremely low to extremely high water. The mean daily flow is ascertained from the field data thus secured. The records are published in the annual water-supply papers of the United States Geological Survey and may be obtained from the Columbus office of that bureau, which is located in the Engineering Experiment Station building at the State University.

To obtain all the facts about the discharge of streams requires many years work and this has only been started. The records which for the Scioto date from April 1, 1921, and for the Olentangy from December 15, 1923, are as follows:

Scioto River below O'Shaughnessy Dam, near Dublin

Location.—A quarter of a mile north of line between Delaware and Franklin counties, three-fourths mile below O'Shaughnessy dam, and 3 miles north of Dublin.

Drainage area.—988 square miles (measured on topographic maps).

Gage.—AU water-stage recorder on left bank three-fourths mile below O'Shaughnessy dam, installed October 14, 1924. From August 26, 1921, to October 13, 1924, vertical staff in three sections on left bank 100 feet below present location. From April 1 to August 25, 1921, vertical staff in several sections on left bank at site of O'Shaughnessy dam. Zero of gage is 775.00 feet above mean sea level. Recorder installed and maintained in cooperation with city of Columbus.

Discharge measurements.—Made from cable half a mile above gage or by wading.

Extremes of discharge.—Maximum stage recorded during period of record, 11.9 feet at 12 M. March 29, 1924, (discharge, 19,400 second-feet); minimum stage, 2.21 feet from 1 to 4 p. m. November 8, 1924 (discharge, 0.4 second-foot).

The great flood of March, 1913, reached a stage on March 25 of 24.6 feet referred to gage datum, and the flow was estimated at 80,000 second-feet.

Regulation.—Beginning in November, 1924, water was stored in O'Shaughnessy reservoir. Monthly summaries of flow have been corrected for this storage.

Month	Discharge in second-feet				Run-off in inches
	Maximum	Minimum	Mean	Per square mile	
1921					
April	4,620	484	1,630	1.65	1.84
May	4,120	167	949	.961	1.11
June	274	42	97.1	.098	.11
July	73	26	37.2	.038	.04
August	73	9	29.4	.030	.03
September	68	11	27.9	.028	.03
1921-22					
October	50	19	28.2	0.028	0.03
November	5,520	95	1,480	1.50	1.67
December	5,290	401	1,150	1.16	1.34
January	2,400	109	491	.497	.57
February	3,800	156	1,230	1.24	1.29
March	7,240	394	2,050	2.07	2.39
April	10,800	338	3,380	3.42	3.82
May	8,280	258	2,060	2.09	2.41
June	2,250	75	439	.444	.50
July	1,320	40	286	.289	.33
August	103	26	47.3	.048	.06
September	230	25	64.6	.065	.07
The year	10,800	19	1,060	1.07	14.48

Month	Discharge in second-feet				Run-off in inches
	Maximum	Minimum	Mean	Per square mile	
1922-23					
October	37	24	28.5	0.029	0.03
November	47	23	31.7	.032	.04
December	1,820	25	198	.200	.23
January	4,000	419	1,560	1.58	1.82
February	2,560	150	865	.876	.91
March	5,290	335	1,940	1.96	2.26
April	2,720	132	570	.577	.64
May	9,910	75	1,760	1.78	2.05
June	732	44	176	.178	.20
July	593	30	111	.112	.13
August	175	28	81.2	.082	.09
September	413	25	111	.112	.12
The year	9,910	23	621	.629	8.52
1923-24					
October	109	30	48.5	0.049	0.06
November	289	52	99.8	.101	.11
December	7,750	86	2,850	2.88	3.32
January	8,290	....	1,670	1.69	1.95
February	3,610	....	1,030	1.04	1.12
March	18,200	365	2,970	3.01	3.47
April	6,240	208	771	.780	.87
May	880	235	437	.442	.51
June	8,570	359	2,260	2.29	2.56
July	1,620	58	569	.576	.66
August	208	32	62.2	.063	.07
September	57	32	38.4	.039	.04
The year	18,200	30	1,070	1.08	14.74

Month	Discharge in second-feet					Corrected
	Actual			Corrected		Run-off in inches
	Maximum	Minimum	Mean	Mean	Per square mile	
1924-25						
October	52	22	30.2	30.2	0.031	0.04
November	68	.4	29.6	34.5	.035	.04
December	990	25	275	338	.342	.39
January	173	46	78.1	44.5	.045	.05
February	3,060	160	1,090	1,340	1.36	1.42
March	4,840	638	1,640	1,490	1.51	1.74
April	683	21	181	115	.116	.13
May	68	2	46.4	58.3	.059	.07
June	79	53	62.5	61.3	.062	.07
July	60	46	55.1	66.5	.067	.08
August	53	44	47.2	40.2	.041	.05
September	85	1	61.5	124	.126	.14
The year	4,840	.4	296	305	.309	4.22

Olentangy River near Delaware

Location.—Prior to December 15, 1923, at William Street bridge in Delaware, Delaware County. Beginning that date at highway bridge a quarter of a mile north of the Pennsylvania Railroad crossing 4 miles north of Delaware.

Drainage area.—415 square miles at original location, and 387 square miles at new location (measured on topographic maps).

Records available.—October 1, 1921, to September 30, 1925.

Gage.—Chain gage at original station on Winter Street bridge, read by D. H. Leas. Zero of gage 848.58 feet above mean sea level. AU water-stage recorder at new station. Zero of gage 876.92 feet above mean sea level.

Discharge measurements.—Made from highway bridges near gages or by wading.

Extremes of discharge.—Maximum stage recorded during period of record, 11.3 feet at 5:30 p. m. May 20, 1922 (discharge, 15,000 second-feet); minimum stage recorded, 0.45 foot at 12 m. September 12, 1925 (discharge, 0.2 second-foot). In the great flood of 1913 the discharge was estimated at 60,000 second-feet.

Month	Discharge in second-feet				Run-off in inches
	Maximum	Minimum	Mean	Per square mile	
1921-22					
October	71	5.6	17.9	0.043	0.05
November	3,140	54	788	1.90	2.12
December	2,460	129	676	1.63	1.88
January	1,690	48	297	.716	.83
February	2,060	58	733	1.77	1.84
March	3,230	144	1,120	2.70	3.11
April	5,810	121	1,180	2.84	3.17
May	8,600	101	1,160	2.80	3.23
June	2,140	51	280	.675	.75
July	545	13	123	.296	.34
August	286	6.1	56.4	.136	.16
September	785	8.3	83.4	.201	.22
The year	8,600	5.6	542	1.31	17.70
1922-23					
October	12	5.1	9.29	0.022	0.03
November	50	7.8	16.5	.040	.04
December	1,690	14	172	.414	.48
January	3,140	216	961	2.32	2.68
February	1,340	96	494	1.19	1.24
March	3,140	162	825	1.99	2.29
April	2,540	82	342	.824	.92
May	11,600	45	889	2.14	2.47
June	900	25	170	.410	.46
July	302	11	58.6	.141	.16
August	149	5.5	32.4	.078	.09
September	228	7.5	46.9	.113	.13
The year	11,600	5.1	336	.810	10.99

Month	Discharge in second-feet				Run-off in inches
	Maximum	Minimum	Mean	Per square mile	
1923-24					
October	36	7.1	15.3	0.037	0.04
November	143	28	57.8	.139	.16
December	6,440	186	1,610	4.03	4.65
January	5,180	....	812	2.10	2.42
February	2,040	168	449	1.16	1.25
March	6,350	168	1,130	2.92	3.37
April	847	82	218	.563	.63
May	297	92	164	.424	.49
June	4,100	105	781	2.02	2.25
July	987	14	163	.421	.49
August	17	4.8	8.85	.023	.03
September	27	3.8	8.25	.021	.02
The year	6,440	3.8	454	1.16	15.80
1924-25					
October	43	5.7	12.4	0.032	0.04
November	14	7.9	11.0	.028	.03
December	1,380	7.6	176	.455	.52
January	....	....	27.5	.071	.08
February	4,020	....	863	2.23	2.32
March	2,090	108	585	1.51	1.74
April	1,230	46	133	.344	.38
May	103	25	47.4	.122	.14
June	101	6.3	23.6	.061	.07
July	495	7.2	103	.266	.31
August	119	2.4	24.0	.062	.07
September	1,290	.3	142	.367	.41
The year	4,020	.3	174	.450	6.11

Special Features of Minor Valleys

Profiles.—Tributary streams were originally consequent; at the start they were not in V-valleys, but followed shallow depressions in the surface of the drift. As the main streams into which they emptied deepened their valleys, the tributaries cut down, deepening first their lower sections, and then progressively up-valley. The result is that the profile of the lower part of the valley is the normal concave profile due to headwater erosion of the tributary, subsequent to the down-cutting of the larger valley into which it enters. Somewhere in the middle or upper part of the valley this curve, concave up, passes into the flatter slope of the part of the valley which has been but little deepened below the general drift surface. Toward the head one goes up through the shallowing valley with lessening gradient, until all trace of stream-shaped valley is lost in a gentle down-roll of the glacially fashioned surface of the upland. The lower, stream-shaped part of the valley is pushing its way by headwater erosion back along the course of the upper part of the valley which was shaped by the glacier, and in this way subsequent drainage is replacing consequent drainage throughout the lower parts of all tributaries entering larger deepened valleys. Plate XII A is a view of the lower part of a small tributary where the stream has cut a deep V-shaped valley.

Valley flats and low terraces.—The lower parts of many of the smaller tributaries have developed alluvial flats, in which the processes of stream erosion are excellently shown. As the streams have continued to cut down since entering on their period of lateral swinging and flat formation, they have developed low rock terraces veneered with alluvium. Such terraces are distinguished from similar forms cut in gravel fillings in valleys by the fact that rock shows in the face of the terrace. Figure 24 is a cross section of the ravine below Greenwood Lake, Dela-

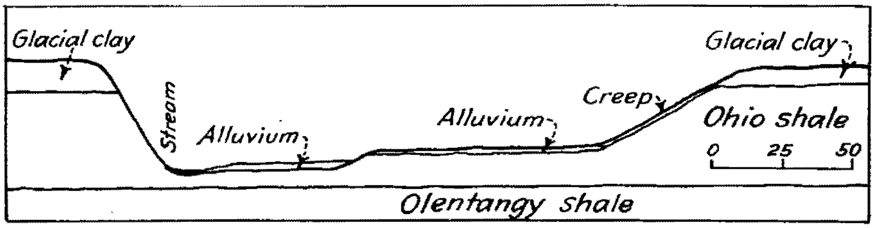


Fig. 24. Cross-profile ravine below Greenwood Lake.

ware, and shows one of these terraces. Since it began cutting the flat shown in the figure the stream has deepened its channel five feet in the shale bed-rock. These sections in the side tributaries are in every essential feature like the sections across the main valley (Figure 23); they differ only in their smaller scale and in the particular kind of bed-rock into which they have been cut. These low terraces are not to be confused with the terrace remnants described in the following section; they are characteristic of a later stage in the erosion of the tributary valley.

Terrace remnants.—The middle sections of most of the tributary valleys entering the Olentangy below Delaware have a series of terrace remnants, which are to be distinguished from those just described. They are higher above the stream level and were developed at an earlier stage in the formation of the valley. Figure 25 is a cross section and Plate XII B a photograph of one of these terraces on Mill Creek in East Delaware. The terrace is not due to harder rock, as it is cut in Ohio shale, some distance beneath the top of the formation. It is a stream-cut flat, formed when the cross section of the valley was ABCD. Some of the terraces are capped by alluvial material, and often they are abun-

A.—Young valley, tributary to the Olentangy at Delaware. Note its V-like shape in cross section.

B.—Terrace remnant on Mill Creek, East Delaware. The three highest men are on the terrace. Stream flows to right and has removed the upstream side of the nose on which the terrace is.

dantly spotted with boulders washed out from the drift during the cutting of the upper part of the section. Since then the stream has cut the inner trench, shown in the section; and up and down the valley has by lateral swinging and down-valley progress cut away most of the terrace, so that today it exists as a series of remnants. The double period of valley cutting can be connected with the downward erosion of the main river. When the main river first reached bed-rock it ceased to cut quickly, and a temporary base level was established for the side streams. During this delay the tributaries cut the upper part of their valleys (Fig. 25 ABCD). Later the main stream cut into bed-rock, and the side streams cut below their upper level to their present position. This may have been aided by the natural lowering of the gradient that would take place with the passage of time, even were the vertical position of the mouth of the stream unchanged.

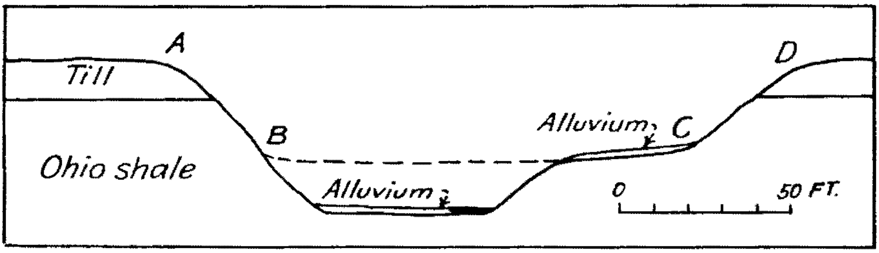


Fig. 25. Cross-profile Mill Creek Valley, East Delaware, showing alluvial terrace at C.

The terrace (Plate XII B) is on a point or nose, around which the stream bend passes. The stream flow is to the right, so that the cliffed side of the nose is on the up-valley side. The down-valley side of the nose is not clearly shown, but it drops back to a flat which the stream has built against the down-valley side of the nose. These conditions are general on the noses, and prove the down-valley progress of the stream curves.

Side-hill gullying and slumping.—Delaware County was originally forested. Clearing the forest has given opportunity for gullying on certain steep slopes. This is not important, as the county as a whole is so level. It is favored by the clayey character of the till.

A process more generally at work on cleared slopes is side-hill slumping. The glacial clay becomes saturated with water, and, no longer held by the root system of the forest trees, develops small landslides (slumps). In this way the transfer of material to the streams is materially hastened.

The Cycle of Erosion

When the ice withdrew from Delaware County a peneplain veneered with glacial till was exposed to stream erosion—a plain averaging 1,000 feet above sea level. That plain is today in a stage of topographic youth. Where the main streams have cut deepest they have not gone more than 50 feet into rock and they are actively cutting down on rock. Tributaries are working back by headwater erosion and bringing more and more of the county to that hillside condition where the rainfall is carried rapidly to the rivers. Yet an inspection of the topographic map shows that large sections of the county are flat and poorly drained. The work of the streams is largely ahead. The county, from the point of view of the erosion changes which any land area exposed to stream erosion must go through, is at the beginning. It is in its youth.

It is possible, in the light of what is commonly known of stream processes, to look ahead and prophesy of the future. The tributaries will continue to work back by headwater erosion and by the development of tributaries of their own until all of the county has valleys and the surface is sloping. The main streams will continue to deepen their valleys until instead of flowing nowhere less than 750 feet above sea level they will be several hundred feet lower, ultimately so near sea level that there is only slope enough to carry the run-off to the Gulf of Mexico. As the main streams cut down the tributaries will follow until Delaware County becomes hilly, perhaps like parts of southern and eastern Ohio today. Later the interstream hills will get lower and lower and finally the county will be part of a new lowland (peneplain) not far above sea level.

It is possible to prophesy—and quite safe. If certain estimates are at all correct, the glacier left the county several tens of thousands of years ago, say 25,000 years. In that 25,000 years only the beginning has been made in the cycle of erosion changes which will end in the production of a peneplain, which event is far off not only in years but geologically. No one will ever be able to show, at least while we are in this world, that we are false prophets.

CHAPTER V

ECONOMIC GEOLOGY

Clays

Surface glacial clays.—Two kinds of clays are found in the county, bed-rock clays, the Olentangy, Ohio, and Bedford, and the surface glacial clays.

For a good many years the largest clay plant in the county was in east Delaware, recently known as The National Fireproofing Co. The plant is located on the western edge of the Ohio shale outcrop and used both the surface glacial clay and the Olentangy clay shale. To get the latter the cover of Ohio shale was stripped and the upper ten feet of Olentangy, down to the first continuous layer of limestone concretions, was quarried. The increasing overload of shale as the workings were carried east finally led to mining the Olentangy. Operations have now (1926) ceased and there is no sign that the company intends to resume work. The company manufactured tile and hollow brick, using the surface clay and the Olentangy in the proportion of three to one.

The only large company in the county now (1926) engaged in the manufacture of clay products is the Delaware Clay Company. The plant is in the southeast part of Delaware, east of the river, and it uses the surface glacial clay. Drain tile and hollow building brick, chiefly the latter, are manufactured. At the present time it is using about 150 cubic yards of clay a day, or 50,000 yards a year.

Ohio shale.—The Ohio shale has been used in making sewer pipe, tile, and brick for many years in Columbus and the products have had a wide sale, though at present its use has practically ceased. The presence of organic matter, lime carbonate, and pyrite in the rock, and the irregular variation in character both horizontally and vertically make its use unsatisfactory. Bownocker[1] states:

> "While these shales may be used for the more common products such as bricks, drain-tile and sewer-pipe, they are not well adapted for any. The composition may vary rapidly in vertical section and areally, making the product hard to control in the kiln and the result uncertain.
>
> "Frequently considerable carbon is present, the residue of marine plants of the Devonian sea. The combustion of this, while the clay is burning, may, under certain conditions, produce too high a temperature, fusing the clay, and of course warping

[1]Geol. Survey Ohio, Bull. 14, Geology of the Columbus Quadrangle, p. 118.

the tile or brick. Sulphur also is present in varying quantity, and sometimes concretions of pyrites (sulphide of iron) are common. The effect of sulphur depends quite largely on its condition, that is, whether it is free or combined with other elements. Often it appears on the surface of the finished product as a white coating that is unsightly and of course injures the sale.

"Calcium carbonate is another substance that is nearly always if not always present. In certain layers this may comprise a large part of the mass while in others it may be very small or possibly wanting. The effects of this are various, depending in part on the proportion and on the other substances present. It may promote fluxing, and if abundant acts as a bleaching agent, so that the product has a buff color.

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

"Products made from these shales burn to a light red, but a higher temperature darkens the shade somewhat."

The Ohio shale has not been worked at any time in Delaware County. A chemical analysis of the shale is quoted on page 38.

Bedford shale.—The Bedford shale makes a north-south belt across the county. South in Franklin County, at Taylors, it is used for making brick. The formation, which is well exposed along the east bank of Big Walnut Creek below Galena, is from 50 to 60 feet thick and contains an abundant supply of clay. The one plant to use it in Delaware County, The Galena Shale Tile and Brick Company, started work at Galena in 1926.

Limestone

The limestones of the western half of the county have been used for making lime, for road materials, for building stone, and for fertilizer. Of the three limestone formations, the Monroe, Columbus, and Delaware, only the last two are today used. There are several small abandoned quarries in the Monroe dolomite; but the Monroe cannot be profitably worked in competition with the thicker, more accessible, and better placed Columbus and Delaware limestones.

Lime.—In the earlier days lime kilns were operated at several places in the county, using mainly the upper half (Klondike beds) of the Columbus limestone. Today but one plant is engaged solely in the production of lime, that of the Scioto Lime and Stone Company, on the east side of the Scioto, three-quarters of a mile south of the Springfield branch of the Big Four. The rock used is the upper forty feet of the Columbus limestone (the Klondike beds), and a very little of the overlying Delaware, the contact between the two being about four feet below the top of the east face of the quarry. The section is given in Figure 6, page 24. Twelve kilns have been completed, and six more are to be constructed. The limestone passes through the kilns in 36 hours, reaching a maximum temperature of 1,800° F. The lime is drawn every three hours. After cooling it is taken to the hydrators, horizontal cylindrical revolving chambers, of which there are two. The larger is forty feet long by seven in diameter. Here 22 per cent of water is added to the lime charge. From the hydrators it goes to the screens. The finer material, which has passed a 30 mesh screen, is bagged and sold as chemical lime. The part which passes the 12 mesh screen, but does not pass the 30 mesh, is bagged and sold as mason's lime or agricultural lime. A small amount of lime is not hydrated but sold in bulk as quicklime. The present output is about 125 tons per day, and the amount of rock used is about 250 tons per day.

The following analyses show the composition of the rock used and of the lime produced:

ANALYSES OF ROCK AND LIME AT PLANT OF SCIOTO LIME AND STONE CO.

	Limestone				Quick-lime	Masons' hydrate			Agricultural hydrate
	1	2	3	4	5	6	7	8	9
Lime, CaO	48.30				88.6	84.7	69.4	66.5	66.2
Magnesia, MgO	5.61				7.8	10.5	8.7	6.9	6.9
Carbon dioxide, CO_2	44.08								
Silica, SiO_2	1.63				2.9	1.7	1.4	.1	1.6
Alumina, Al_2O_3	.39				.7	3.1	2.5	1.4	1.5
Ferric oxide, Fe_2O_3	.19								
Phosphorus pentoxide, P_2O_5	.01								
Titanic oxide, TiO_2	.01								
Manganous oxide, MnO_2	.02								
Carbon, C(organic)	.09								
Sulphur, S	.08								
Water, H_2O (at 105° C)	.03								
Water, H_2O (ignition)							18.	25.1	23.8
Calcium carbonate, $CaCO_3$	87.50	94.6	92.6	92.64					
Magnesium carbonate, $MgCO_3$	11.78	2.8	4.8	4.75					
Silica, SiO_2	1.63	2.1	1.3	1.30					
Iron, Fe_2O_3 and Alumina, Al_2O_3	.58	.5	.3	.28					
Total	100.44	100.	100.	98.97	100.	100.	100.	100.	100.

1. Analysis made (1925) by D. J. Demorest for the Geological Survey of Ohio of sampled working face of the quarry.

2, 3, 5–9. Analyses furnished by the company, analysts unknown.

4. Quoted from Bull. 4, Geological Survey of Ohio, p. 61. Analysis of the beds at White Sulphur, analyst unknown. No. 3 is a generalized statement of No. 4.

The upper half of the Columbus limestone, some 40 feet in thickness, with essentially the same character and composition as that at the plant of the Scioto Lime and Stone Company, extends entirely across the county and furnishes an indefinite supply of high grade lime rock. It was formerly used in several kilns southwest of Radnor. Analysis 6, page 46, shows the composition of the rock north of Radnor, made from sampled borings on the land of Mr. J. T. Herrick.

The American Crushed Rock Company has a large quarry just west of White Sulphur station on the Springfield branch of the Big Four Railroad. The working face is 26 feet high and 1,400 feet long, with fifteen feet of clay overburden. The rock section is given on page 23. The lower 22 feet, the Bellepoint member of the Columbus limestone, is used for railroad ballast and for concrete. The finest dust from the crushing, which will pass a 200-mesh screen, is removed by suction and sold for agricultural lime. The upper 8 feet is used for making hydrated lime. Six kilns are in operation.

The output of the plant is forty to seventy-five 55-ton cars of stone and 50 tons of lime per day.

Road materials.—Limestone for road materials is abundant in Delaware County, and is the only bed-rock used for that purpose. The shales are not suitable for this purpose, and the Berea sandstone along the Big Walnut is too soft and crumbling. The Monroe dolomite along the west side of the county is not used. It would seem to be satisfactory, so far as the stone itself is concerned; but its scanty outcrops and its position put it at a disadvantage compared with the Columbus and Delaware limestones. Both these are used, and make good material. The tests in the following table are taken from a list furnished by the State Highway Department, and were made in its laboratory:

Tests of Stone for Highway Construction

	Abrasion	Hardness	Specific Gravity	Absorption	Toughness	Grade	Formation
1....	4.	17.	2.73	.7	7.	A	Columbus
2....	7.8	10.9	2.27	6.9	3.5	C	Columbus
3....	5.4	13.6	2.29	5.8	4.5	C	Columbus
4....	6.3	11.9	2.22	5.6	5.5	B—	Columbus
5....	3.6	15.3	2.64	1.4	5.	B	Columbus
6....	7.9	13.7	2.57	.6	5.	B	Columbus
7....	6.1	16.6	2.71	.4	6.	A—	Columbus
8....	3.5	17.4	2.72	1.3	10.	A	Columbus
9....	6.3	16.5	2.68	1.2	6.5	B	Delaware
10....	5.3	16.4	2.65	1.	6.5	A	Delaware

1–5. White Sulphur Stone Co. quarry; now American Crushed Rock Co., at White Sulphur, west of the Scioto River.
6. Scioto Lime and Stone Co., the Klondike quarry.
7. Jones quarry, Radnor.
8. Carter quarry, Radnor.
9. Scioto Lime and Stone Co., the Klondike quarry. Top layers.
10. Quarry west of Hocking Valley, at Delaware.

Abrasion.—Five grams of broken stone is placed in a cylinder 34 cm. long by 20 cm. in diameter, and set at an angle of 30° to the horizontal. The cylinder is turned for 10,000 revolutions at 30 to 33 revolutions per minute. The amount of debris produced that will pass a $\frac{1}{16}$ inch mesh sieve, stated in percentage of the original 5 grams of rock used, is the abrasion value.

Hardness.—The faced ends of a cylinder of rock 1 inch in diameter are held in turn under pressure on a revolving disk upon which silica sand is fed. The hardness is 20, minus the loss in weight of the cylinder divided by three.

Absorption.—The increase in weight after immersion of a 1000-gram sample in water for 24 hours.

Toughness.—Three cylinders of rock 2 cm. high by 2 cm. in diameter are cut in different directions from the rock to be tested. A hammer weighing one kilogram and having a hemispherical base rests on the end of the cylinder. A 2-kilogram weight drops on the hammer from heights of 1, 2, 3, etc., cm. successively. The height from which the hammer drops which finally cracks the rock gives the toughness measure. Three tests are averaged to give the values in the table.

The specifications of the State Highway Department for Grades A, B, and C of limestone are as follows:

	Composition	Abrasion	Hardness	Toughness
Grade A	$CaCO_3$ = not less than 60% or $CaCO_3+MgCO_3$ = not less than 65%.	6 or under	15 or over	6 or over
Grade B	$CaCO_3$ = not less than 60% or $CaCO_3+MgCO_3$ = not less than 65%.	8 or under	12 or over	5 or over
Grade C	$CaCO_3$ = not less than 55% or $CaCO_3+MgCO_3$ = not less than 60%.	12 or under	X	4 or over

The tests available give a higher ranking to the Delaware than to the Columbus stone. An inspection of the two stones shows that the Delaware stone is a fine-grained, compact rock with few fossils. The upper half of the Columbus limestone is an abundantly fossiliferous and coarsely granular rock, which would apparently weather more quickly when exposed to weathering in the road bed, just as it weathers much more readily than the Delaware in both quarry walls and natural exposures. The lower part of the Columbus limestone, the dolomitic Bellepoint member, is a soft granular stone. The testimony of those officials and others, who are acquainted with the use of stone in road construction in the county, and with the way the different types have worn, is that the Delaware "blue" stone is superior to the Columbus "gray" stone, that it alone should be used for the surface, and that it is better for the foundation. It is doubtful if the Delaware blue limestone has any superior in the State for road work. The county has an inexhaustible supply of it, and should find it the cheapest to use in the long run.

Sand and gravel

Sand and gravel are obtained for local purposes from the bottoms along the rivers, and in the northwestern part of the county from the line of kame and esker knolls and ridges which extend southeast from Prospect to south of Radnor. In the eastern part of the county the high kame knolls about Condit have also furnished sand and gravel.

Building stone.—The Columbus limestone, which has been used in Franklin County for buildings, especially for foundations, has not been used in Delaware County. The Delaware limestone was, however, used quite generally in earlier days, though in recent years only to a small extent for foundations. A number of older residences, and one or two public buildings—the Episcopal Church, and Merrick Hall at Ohio Wesleyan University—are built of this stone. Along the Olentangy the stone was used in several buildings and mills. The failure to continue the use of the Delaware blue limestone is to be regretted. In the lower part of the formation at Delaware there are thick beds without shale partings suitable for building, and if the material is carefully selected it makes a durable, handsome stone. There is pleasure in finding in the county these old stone buildings, made of local stone; they give the impression that in an unusual sense they "belonged."

The Berea sandstone, so extensively quarried in the northern part of the State, is not now worked in Delaware County. The beds are too thin and irregular to make a satisfactory building stone.

Water Supplies

Domestic wells.—Wells in the bottom lands or gravel terraces along the rivers reach an abundant supply at slight depth, as the underlying alluvium is commonly sand or gravel which allows the ready passage of water.

Back from the streams on the upland areas, which make $\frac{9}{10}$ of the county, the surface mantle-rock is an impervious glacial boulder-clay or till. Wells dug in it do not get water unless they strike a sand layer. Such sand layers are local and unreliable. They may be up in the till or at the bottom, resting on the bed-rock. Figure 26, A and B, shows wells reaching sand seams and giving supplies satisfactory in proportion to the size of the seam. Figure 26 C is a well which fails to strike sand; it must be continued by drilling in the underlying bed-rock until a flow of water is reached. The generally clayey character of the till, with only occasional layers of sand, make it a matter of uncertainty whether water will be found in the till. In some places wells have been dug through the till (20 to 40 feet) and then continued by drilling in rock to a total depth of a hundred feet before water was obtained.

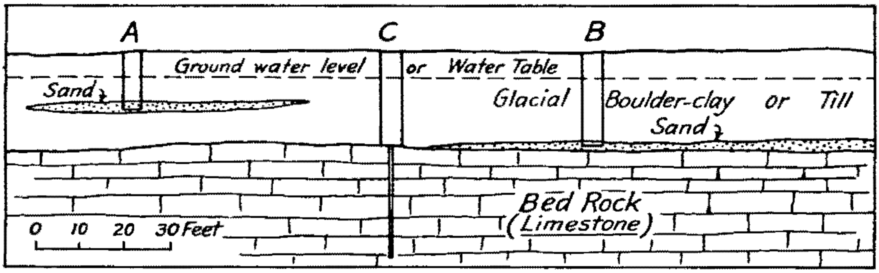


Fig. 26. Ground water conditions in till uplands.

Private domestic wells are liable to contamination from surface wash or underground seepage. Leaky cesspools or sewers may discharge into the same sand from which the well gets its water. The danger of contamination from such a source is greatest for wells in the bottoms, for there one continuous sand or gravel layer underlies the whole bottom. In thickly settled areas, like the city of Delaware, where the location of cesspools and sewers is unknown or has been forgotten, the need of caution in the use of well water is evident. It is an interesting fact that at Delaware no case of typhoid has been traced to the city supply, while many cases have been traced to domestic wells.

Public supplies.—The problem of securing adequate supplies of good water for interior cities in level country is one of increasing difficulty. In a level region all of the land tends to come under cultivation, and the establishment of reservoirs and catchment basins is prevented both by the surface flatness and by the value of the land for other purposes. Underground sources of supply are of minor value, and quickly become insufficient with the increase of population.

The preceding description of well conditions about Delaware shows that no adequate general supply is to be found in the uplands. For many years the water supply for the city of Delaware was derived from wells dug in the bottom lands on the west side of the Olentangy River a little over two miles north of the city limits. The first well put down was thirty feet in diameter, was dug to bed-rock, and thus furnished water from the river bottom gravels. When this proved inadequate several wells were drilled into the limestone bed-rock to distances of about 200 feet. Still later a series of driven wells was added, ranged along the edge of the river, in the expectation that the river water would seep through into them, and be filtered on the way. What water was finally obtained from these wells was from the bottoms to the west rather than from the river; in part because the general flow of the ground water in any flat is toward the river, in part because the fine river silt deposits along the inside face of the bend blocked inflow from the river.

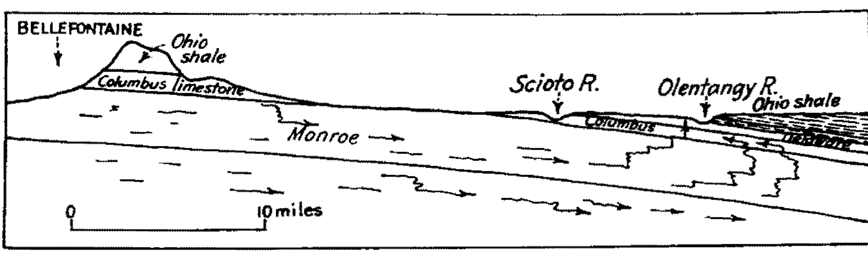


Fig. 27. Underground water flow, Delaware County.

With the increasing water demands of the city the total underground supplies of the Delaware Water Company became insufficient. Today the use of water from the wells has been abandoned and the city's supply is taken directly from the river. Carbonate of soda, quicklime, and alum are mixed with the water, which is then taken to settling basins. The carbonate of soda changes the sulphates of lime and magnesia in solution in the water to carbonates. The lime is added to change these soluble bicarbonates to insoluble carbonates. The alum precipitates the suspended mud, so that in the settling basins mud and original carbonates are largely eliminated. The same process takes care of most of the bacteria, which are finally removed by the addition of chlorine.

The aim of the company is to furnish water which is clear, shows a negative test for colon bacteria in 10 cc. of water, and has a hardness of less than 100 per 1,000,000 (.01%).

Composition of Olentangy River Water[1]

Descriptions and Chemical Analyses (parts per million)

Location	Date collected	Color	Turbidity	Sediment	Odor	Nitrate ion (NO_3)	Chloride ion (Cl)	Carbonate or temp. hard. ($CaCO_3$)	Non-carbonate or permanent hard. ($CaCO_3$)	Total hardness	Total solids
Delaware,											
above town....	6–10–97	.2	Slight......	Slight......	Faint musty......	0.5	3.5	204.	16.	220.	355
" "	7–15–97	.5	Strong.....	Marked....	Musty...........	0.5	2.0	164.	22.	186.	350
" "	8–24–97	.2	Slight......	Distinct....	None............	0.1	2.0	202.	44.	246.	385
" "	9–24–97	.2	Slight......	Slight......	Slight musty......	0.0	2.0	202.	66.	268.	435
" "	10–26–97	.2	Clear......	Very slight.	Very slight, earthy.	Trace	3.0	226.	120.	346.	550
" "	12– 2–97	.8	Marked....	Slight......	Musty...........	21.7	2.3	120.	96.	216.	376
Average.....	....	....	....	....	....	3.8	2.5	186.	61.	247.	408
Delaware,											
below town....	6–10–97	.25	Very slight.	Very slight.	Faint musty......	0.9	4.7	202.	28.	230.	355
" "	7–15–97	.5	Strong.....	Marked....	Musty...........	2.8	4.0	152.	30.	182.	330
" "	8–24–97	.25	Slight......	Distinct....	Very slight musty.	0.8	7.7	206.	62.	268.	405
" "	9–24–97	.2	Very slight.	Slight......	Musty...........	0.5	15.7	236.	80.	316.	515
" "	10–26–97	.25	Very slight.	Very slight.	Musty...........	0.4	51.5	260.	142.	402.	710
" "	12– 2–97	.6	Marked....	Slight......	Musty...........	15.9	3.3	122.	102.	224.	374
Average.....	....	....	....	....	....	3.6	14.5	196.	74.	270.	448

[1]Geol. Survey Ohio, Fourth Series, Bull. 29, p. 204.

All water from private wells, and the city water, so long as it was taken from wells, was hard. This is unavoidable, since it comes from the limestone, or from the till, which contains both abundant limestone blocks of all sizes and a large amount of finely powdered limestone (glacial rock-flour). An analysis[1] by Prof. N. W. Lord of the mineral content of the city water, when it was taken from underground sources, gave the following results in grains per gallon:

Sodium sulphate	1.58	19.02	Sulphates
Potassium sulphate	.44		
Calcium sulphate	17.00		
Calcium carbonate	11.00	22.75	Carbonates
Magnesium carbonate	11.75		
Sodium chloride	.22	.22	Chlorides
Silica and silicates	1.11	1.11	
Total	43.10		

This shows about equal parts of carbonates (22.75 grains) and sulphates (19.02 grains). The carbonates come from the solution of the limestones and dolomitic (magnesian) limestones which are the bed-rock of the region west of the river, and which occur as boulders, stones, and rock flour in the till. The calcium sulphate is a result of the action of sulphuric acid on the calcium carbonate. The sulphuric acid comes from the oxidation of pyrite (iron sulphide, FeS_2) which is everywhere present in the limestones and shales.

When this water is boiled the lime carbonate, which exists in solution as the soluble bicarbonate of lime ($H_2Ca(CO_3)_2$ or $H_2O.CO_2.CaCO_3$) loses its CO_2 and is changed to the insoluble monocarbonate, $CaCO_3$. This is precipitated, and is what makes the earthy lining of water kettles in which water has been heated, even if it is not evaporated.

The public water supply for Sunbury is obtained from rock wells drilled north of the village. Several wells have been drilled. In the spring of 1926 one well, a six-inch well, drilled to a depth of 70 feet, furnished the total supply, and another well was being drilled, a depth of 300 feet having been reached, but no water obtained.

Springs.—Two classes of springs are to be distinguished: bedding-plane springs and fissure springs.

Bedding-plane springs in regions like Ohio, of horizontal rock, are found along valley sides where an impervious bed of rock outcrops, overlain by a permeable bed. The best local example is at the contact of the Ohio and Olentangy shales. The Olentangy is a soft impermeable rock. The overlying Ohio, while fine grained and impermeable in the hand specimen, is abundantly fissured. The ground water works its

[1]Preliminary report of an investigation of rivers and deep ground waters of Ohio, as sources of public water supplies, State Board of Health, p. 215, 1898. Additional analyses may be found in Bulletin 29, Geol. Survey Ohio, p. 294.

way through the cracks in the Ohio shale, just above the surface of the Olentangy, and comes out where the contact plane cuts the valley side.

Fissure springs are those that come to the surface through cracks or joints in the rock and are independent of any contrast between permeable and impermeable layers. Usually the joints make a large angle with the horizontal, as is true for many of the springs coming up in the rocky beds of the Scioto and Olentangy valleys. But even if the joint is a horizontal bedding-plane joint, the spring is a fissure spring, if the controlling factor is the joint and not relative permeability. Many of our fissure springs come out along horizontal cracks in the limestone.

Springs are more common and have larger flow in the limestone of the western half of the county, for in the limestone solution has enlarged the openings, and the water may flow underground with the ease of water flowing through a system of pipes.

Mineral springs.—All underground water contains some mineral material in solution, dissolved from the surface mantle-rock and bed-rock through which it has passed. Mineral springs are those which contain a noticeable amount of such mineral matter, noticeable either to the taste or because of the deposits made at the point of exit. Mineral springs of three kinds are found in Delaware County:

1. Sulphur-saline springs.
2. Iron springs.
3. Lime carbonate springs.

Sulphur-saline springs

Sulphur springs are known by the smell of the hydrogen sulphide (H_2S) gas in solution in the water. This gas can be driven off by boiling and the water is then odorless. When the water is evaporated to dryness a white residue is left which tastes like common salt and which is in fact largely salt ($NaCl$). The sulphur springs are then actually sulphur-saline springs. It was springs of this kind which made the "salt licks" of the early days in the upper Ohio Valley, furnishing salt to the first settlers.

The following quaint account of the sulphur springs of Ohio of the early days of the State is taken from the First Annual Report on the Geological Survey of Ohio, pages 54-55, published in 1838, nearly a century ago:

"From the period of our first organization as a member of the Union, the "Salt Springs" arrested the attention, and received the fostering care of our legislatures. Even before we had become a State, and were yet "a territory," the great value of the Salines had attracted the notice of our most sage and prudent citizens; and, in the compact made with Congress, distinct and express stipulations were entered into for setting apart the most noted salt springs, and a considerable territory around them. for the benefit of the State; they being considered as too valuable to fall into the hands of individuals, who might create a monopoly. At the present period, when culinary salt is so cheap an article, it may seem strange to us, that our fathers should have been so careful to preserve salines, the waters of which were so weak as to require six hundred gallons to make fifty pounds of salt. But when we remember, that at the period referred to, before this territory became a State, the price of salt varied from four to six dollars a bushel, and that the larger portion of it was brought across the Allegheny ranges of mountains, on the backs of pack horses, we need not wonder at the high value placed upon these saline waters. At that time, they were the only ones known in Ohio, and it was not even suspected or imagined, that at the depth of a few hundred feet, many portions of the valley were based on a rock, whose interstices were filled with exhaustless quantities of brine, of such strength that one twelfth part of the quantity would make a bushel of salt. This article, so valuable, and so scarce in those early days as to be looked upon almost as a luxury, has since been so abundant as to sell for half a cent a pound.

"The all-wise and beneficent Creator, who formed this earth for the habitation of man, has stored it with all things necessary for his comfort and happiness. Geology has disclosed the interesting fact, that in every region remote from the Ocean, He has deposited in the rocky strata of the earth, vast magazines of salt. The interior of Africa, Asia, Europe and America, contain either in the form of rock or native salt, brine springs,lakes or efflloresences,an ample supply for the wants of all the inhabitants."

The characteristic odor of the sulphur spring is due to the hydrogen sulphide gas (H_2S) in solution in the water. The Odevene water at Delaware contains 2.924 cu. in. of H_2S per gallon; the Saniteau water, 3.6. The H_2S has been attributed to the action of carbon, or of methane (marsh gas, CH_4), derived from the carbonaceous matter in the rocks, on the sulphates, especially calcium sulphate in the ground water. The chemical equations which would represent the original and final stages could be written as follows:

$$CaSO_4 + CH_4 + H_2O \longrightarrow CaCO_3 + H_2S + H_2O$$

$$CaSO_4 + 2C + H_2O \longrightarrow CaCO_3 + H_2S + CO_2$$

Production of H_2S in this manner has been recorded from muds of modern sea bottoms, as of the Black Sea, where the process has been considered as due to the action of bacteria. It has been assumed that bacteria were absent in the waters of deep wells and that the H_2S found in such waters was not due to living organisms. Bastin[1] has recently stated that he has been unable to get in the laboratory at ordinary temperatures H_2S from sulphate waters in the presence of organic matter, and has reported bacteria from oil well waters in Illinois at depths of from 450 to 1,700 feet. It seems from this that the H_2S in the local sulphur springs may be due to the action of bacteria, in the

[1]Bastin, E. S., The presence of sulphate reducing bacteria in oil field waters. Science, Vol. 63, pp. 21-24., Jan. 1, 1926.

presence of organic matter, on the sulphates in the ground water. Organic matter, as shown elsewhere in this bulletin, is present, sometimes in large amounts, in all the shales and limestones of the county.

The following table gives analyses of the mineral content of the sulphur springs of Delaware, so far as known. They have been recalculated to a percentage basis.

	1	2	3	4	5	6
Potassium chloride, KCl	5.17	6.		.31	.01	
Sodium chloride, NaCl	40.40	25.02		17.38	11.31	77.8
Lithium chloride, LiCl	tr					
Calcium chloride, $CaCl_2$	4.23					
Magnesium chloride, $MgCl_2$	15.49		11.88		20.36	10.9
Calcium sulphate, $CaSO_4$	28.38	28.16	23.31	24.02	16.02	3.6
Magnesium sulphate, $MgSO_4$		20.78	25.80	31.71	16.02	4.7
Sodium sulphate, Na_2SO_4		12.81		2.30		
Potassium sulphate, K_2SO_4						2.5
Calcium carbonate, $CaCO_3$	5.79	6.55	34.89	23.42	33.86	.3
Magnesium carbonate, $MgCO_3$	.42	.50	2.50	.01	2.08	
Sodium carbonate, Na_2CO_3		.10	.72		.01	
Lithium carbonate, $LiCO_3$			.05		tr	
Iron carbonate, $FeCO_3$				.01		
Calcium phosphate, $Ca_3P_2O_8$			.85		tr	
Alumina, Al_2O_3 / Ferric oxide, Fe_2O_3	.10					
Silica, SiO_2	.10					
	99.08	99.92	99.99	99.16	99.67	99.8
Salinity	.62	1.06	.0725	.1011	.0815	

1. Odevene well, Delaware. Analyst A. A. Breneman.
2. Saniteau well, Hotel Allen, Delaware. Analyst unknown.
3, 4, 5. Springs, Delaware Springs Sanitarium, Delaware. Analyst, H. A. Weber.
6. Analysis of salts in ocean waters, for comparison. From Pirsson and Schuchert, Geology, part 1, p. 91.

The values in the above table are not to be taken too seriously. If the analyses were stated as metals and non-metallic or acid radicals present, it would be easier to compare them.

The mineral content of the Odevene water, which probably comes from the greatest depth, differs from that of surface water (page 122) in two respects: 1. It has a great deal more material in solution, nearly nine times as much. 2. The materials in solution are different. In the city water sulphates and carbonates rule while chlorides are negligible. In the Odevene water chlorides make nearly two-thirds of the total while carbonates make less than one-tenth. Further the metals present in the city water are chiefly calcium and magnesium; in the Odevene water sodium and calcium.

The explanation of the peculiar composition of the Odevene water lies in the fact that it has followed a much longer and a much deeper course. It has thus had a chance to dissolve more materials. But more important, its deeper course has carried it to levels below the surface where it has had the chance to mingle with the brines of the deeper rocks. The rocks below the surface of Delaware County are old sea-bottom sediments and were at the time of their formation saturated with ocean water. This original salt water (connate water) they carried down with them as they settled beneath later overlying sediments, and it is this salt content that the underground circulation has been bringing to the surface ever since the rocks came above the sea and the underground circulation began. The connate waters originally had the composition of ocean water. Column 6 gives an analysis of ocean water. The other analyses do not agree in mineral composition with analysis 6, nor do they agree closely with each other. The salinity is much less than that of ocean water; if it were not, it would be impossible to drink these waters. Their relative content of chlorides is much less than that of ocean water; the content of sulphates and carbonates, particularly the latter, much greater. These differences from ocean water, and the differences that can be noted in the table among analyses 1 to 5, mean that there is dilution and a large contribution of mineral salts from the upper rock levels (carbonates and sulphates of lime and magnesia), and that the waters of the different springs have followed different courses and been influenced thereby in different ways and degrees. The Odevene and Saniteau waters (Nos. 1 and 2) seem to have a larger contribution from deeper sources than do the waters from the Delaware Springs Sanitarium wells, as shown both by the higher salinity and by the larger proportion of chlorides.

The Odevene and Saniteau waters are artesian flows from wells, the former put down 2,200 feet to the Trenton in a vain search for oil, and said to be drawing its present flow from 300 feet down. Many other flows in the county are natural springs, usually flowing out from cracks in the limestone. The Sulphur Spring on the Ohio Wesleyan campus has never been traced to bed-rock.

The sulphur spring waters which are coming to the surface along the Olentangy Valley have followed a deep and long underground course (Fig. 27). The general dip of the rocks is to the east at an average rate of 25 feet per mile. The head for the flow is the high land east of Bellefontaine, which forms the divide between the Miami and Scioto basins. Water sinking through the surface deposits enters the limestones and following joint cracks in the limestones takes a course down and to the east toward the axis of the Scioto Basin. In depth it sinks to at least several hundred feet and may go to over a thousand, certainly deep enough to mingle with the original brines of the limestones. It flows down the dip of the rocks until it comes to the western edge of the Devonian shales. Since exit to the surface is cut off to the east by this cover of impermeable shale, the waters rise to the surface along the western edge of the shale outcrop and to this the numerous springs about Delaware and along the Olentangy are due.

Temperature of springs

The temperature of the ground varies with the seasons, the variation being greatest at the surface and becoming less with depth. Below a certain depth, usually given at about 40 feet in our latitude, the temperature of the ground at any level is constant, unaffected by the seasonal temperature changes at the surface. This is the level of no annual change. The temperature of the ground at this level is the average annual air temperature of the locality. Below this level the temperature, while constant at any one level, increases in depth at an average rate of 1° Fahrenheit for every 60 feet in depth. These temperature conditions must affect the temperature of the ground water. Springs of shallow flow, above the level of no annual change, should be warmer in summer and cooler in winter. Waters rising from below this level and coming to the surface should have a constant temperature through the year, unless they come so slowly through the upper forty feet as to be influenced by the surface ground temperatures. The average annual temperature of Delaware is 51° F. The temperature of the Sulphur Spring is nearly constant and is very close to 51°, the temperature of the ground at the level of no annual change. As the Sulphur Spring is believed to have a deep underground source the uniformity in its temperature is to be expected. If its water comes from any considerable depth it might be expected to have a temperature above 51° F. That it does not is probably because it comes up slowly through a complex network of fissures in the limestone, and cools to the temperature of the rock it passes through.

Iron springs[3]

Iron springs, depositing rusty-brown iron oxide (limonite, $2F_2O_3.3H_2O$), are common through the county. The source of the limonite is the pyrite[1] which occurs in the till, in minute grains in the limestone, and as grains and nodules in the shales, particularly in the Ohio shale. Descending ground water, carrying air in solution, oxidizes the pyrite to the soluble iron sulphate ($FeSO_4$), which is carried in solution to the point of exit where it is further oxidized and precipitated as the insoluble, rusty-brown limonite. It has been shown[2] that certain bacteria, particularly the filamentous bacteria *Leptothrix ochracea*, *Gallionella ferruginea*, *Spirophyllum ferrugineum* are present in the waters of iron

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[1]The iron sulphide is present in the rocks both as pyrite and marcasite, of identical chemical composition. For convenience it is referred to as pyrite.

[2]Harder, E. C., The iron-depositing bacteria and their geologic relations. U. S. Geol. Survey Prof. Paper 113, 1919. This is an excellent summary of the subject.

[3]See note p. 135.

springs and are instrumental in the precipitation of the limonite. All of these forms have been found in the waters of local iron springs. The limonite is then a deposit, in part perhaps purely chemical, in part organic.

The chemical reactions involved in the change from pyrite to limonite may be stated as follows:

1. For the oxidation of the pyrite to the soluble sulphate:

$$FeS_2 \text{ (pyrite)} + 6O = FeSO_4 \text{ (iron sulphate)} + SO_2$$

The ease of this change is shown by the fact that nodules of marcasite standing in the laboratory become covered with white, hairy, acrid-tasting iron sulphate or melanterite ($FeSO_4 . 7\,H_2O$), the needed oxygen and water coming from the ordinary air of the room.

2. For the precipitation of the iron as limonite:

$$4FeSO_4 \text{ (iron sulphate)} + 2O + 7H_2O = 2Fe_2O_3 . 3\,H_2O \text{ (limonite)} + 4\,H_2SO_4 \text{ (sulphuric acid)}$$

Certain collateral results of the oxidation of the pyrite should be mentioned. The Ohio shale is the most pyritic local formation and the waters working out to the surface of the shale cliffs and evaporating often leave a deposit of white or yellowish iron sulphate (copperas or melanterite, $FeSO_4.7H_2O$, wrongly called alum). Hence the occurrence of "copperas banks" and "Alum Creek" as local terms.

In the change from pyrite to limonite, while the iron of the pyrite is kept the sulphur is lost. The equations given above show that the sulphur comes out as SO_2 and H_2SO_4, ultimately all of it as the last. But all of the local ground waters contain calcium carbonate in solution, derived partly from the limestone bed-rock, partly from the till. The H_2SO_4 acts on the $CaCO_3$ to produce $CaSO_4$ according to the following equation:

$$CaCO_3 \text{ (calcium carbonate)} + H_2SO_4 = CaSO_4 \text{ (calcium sulphate)} + H_2O + CO_2$$

The calcium sulphate may remain in solution, but along the outcrops of the shale some of it is precipitated as abundant minute crystals of gypsum ($CaSO_4 . 2H_2O$) in the joints and openings of the shale near the surface.

Lime-carbonate springs

Lime springs deposit carbonate of lime, usually in a porous form, known as travertine. The lime carbonate exists in the bed-rock and in stones and rock flour in the glacial drift. This is insoluble in soil water. But soil water containing carbon dioxide in solution changes the monocarbonate to the soluble bicarbonate. The reaction is:

$CaCO_3$ (monocarbonate of lime) + CO_2 + H_2O = $H_2Ca(CO_3)_2$ (bicarbonate of lime)

The formula for the bicarbonate can also be written $H_2O.CO_2.CaCO_3$, which shows perhaps a little better its constituent parts. When the ground water with the bicarbonate in solution comes to the surface, a part of the carbon dioxide escapes, the bicarbonate breaks down into its original parts, and the resulting insoluble monocarbonate is deposited on the surface. As the material is often deposited over a surface strewn with leaves or covered with moss, it may encrust the leaves and moss and when they die casts of them are left in the travertine.

Some of the largest travertine deposits seen are on the sides of valleys in the shale or sandstone of the eastern part of the county, the bed-rock of which does not contain the carbonate of lime. The material here is leached from the surface till as the rain-water works its way into the soil. The finely divided carbonate of lime has already been leached from the upper four or five feet of the till, and from the upper foot or two even the limestone blocks have almost entirely disappeared through solution. The best example of travertine in the county is a large deposit on the east side of Big Walnut Creek east of Sunbury. The bank here, thirty-five feet high, is covered with a deposit of porous, light-colored travertine several feet thick. The material has been derived from the leaching of the drift covering the surface to the east; the sandstone itself cannot have furnished the carbonate.

Oil and Gas

Neither oil nor gas has been found in Delaware County. As wells have been drilled for oil at several places and as inquiries are frequently made as to the probability of finding oil or gas, it is well to consider what that probability is.

Three formations occur beneath the surface of Delaware County which have furnished oil or gas in other parts of the State[1], the Berea, the Clinton, and the Trenton. They are shown in relation to the general geology of the State in Fig. 3.

The Berea sandstone has furnished gas in parts of eastern Ohio. In this county it occurs from its outcrop along Big Walnut Creek east to the county line where it is under hardly more than a hundred feet of cover. It must therefore be disregarded as a possible local source.

The Clinton sand is the source of oil and gas along a north-south belt in east-central Ohio. The producing rock known as the Clinton usually lies 100 to 150 feet below the Niagara and appears to be a part of the Medina formation. The rock is patchy in nature, so that the

[1]Bownocker, J. A., Petroleum in Ohio and Indiana, Bull. Geol. Soc. America, Vol. 28, pp. 667–676, 1917.

driller cannot be certain of finding sand when he reaches its position. Interesting to report, the sand does not exist west of the longitude of Columbus, and there its position is taken by shales usually.[1] The west boundary of the Clinton producing territory[2] runs some ten miles east of Delaware County. The Clinton sand in the Bremen field is about 800 feet below the top of the limestone series of the State. The place or horizon of the Clinton sand in Franklin County, as shown by wells, is about 780 feet below the top of the limestones. This would put it at Delaware (the top of the Delaware limestone is here at river level and 860 feet above sea level), 780 feet below the surface and 80 feet above sea level. Several wells in Delaware and Franklin counties have gone through the Clinton horizon without finding oil. Apparently beneath Delaware County it has lost its sandy character and is not an oil horizon.

The Trenton limestone, the great producing horizon of northwestern Ohio, lies about 1,100 feet below the Clinton sand, which puts it at Delaware about 1,900 feet beneath the surface and nearly 1,000 feet below sea level. Oil is obtained in northwestern Ohio from the upper part of the Trenton, where the rock is porous and magnesian. This rock was originally non-magnesian; the change to dolomite resulted in shrinkage and cavity formation making it a possible oil reservoir. This condition is local, not general; it is not known to exist in central Ohio. Several wells have been put down to the Trenton in Delaware County and vicinity, but oil has never been found.

If an oil horizon is known to extend beneath a given region the most favorable location for a well will be on or near the crest of an anticlinal rock fold, which is of course quite independent of surface relief. In northwestern Ohio the oil is found collected beneath the crest of a broad low arch or anticline. In Delaware County the general structure is monoclinal, not anticlinal, and so far unfavorable to oil accumulation. The rocks have an average dip of 25 feet per mile to the east. But this dip is an average, it is not uniform. There are places where it flattens, even where it is reversed, as at the limestone quarries in Delaware. But while there are these inequalities, it has not seemed possible to work out structures over the county as a whole in any such way as to suggest possible especially favorable locations. Further, the anticlinal principle would not be applicable in locating wells drilled to the Clinton, since the distribution of oil rock at that level seems to be determined by the patchy distribution of the oil sand. Moreover the Clinton is a dry sand[3] and the oil goes to the lower part of the sand.

Past experience indicates that there is very little chance of getting oil or gas in Delaware County. It is not impossible. Some future

[1]Bownocker, loc. cit, p. 672–3.
[2]Geological map of Ohio.
[3]Bownocker, J. A., The Bremen oil field. Geol. Surv. Ohio, Fourth Series, Bull. 12, p. 24.

well may strike a porous dolomitic part of the Trenton or a local sand at the Clinton horizon; and it is not impossible that local producing sands may be found at some other hitherto unknown horizon—but it is a chance and a long chance. No money should be spent for drilling for oil in Delaware County except by those who are able to lose it.

Oil Shale

The Ohio shale is a low-grade oil shale, as the plant remains in it might suggest. The freshly-broken rock smells oily and when it is heated oil and gas are driven off. Two samples[1] from the lower part of the formation at Glenmary, just south of Delaware County, gave on distillation the following results:

Yield per Short Ton

Sample	Amt. used ounces	Oil gallons	Water gallons	Gas cu. ft.	Ammonia lbs.
1	6	7.7	5.6	1,199	.11
2	6	5.6	5.6	958	.00

These values are low compared with high-grade western oil shales which may run to 20 to 40 gallons per ton. Yet if the Ohio shale is uniform vertically and if it yields seven gallons to the ton throughout its extent, for every square mile of area each 100 feet of the formation would produce approximately 50,000,000 barrels. As the formation varies from nothing at its western edge to 600 feet where it runs below surface and thence thickens east to the county line, this means a very large amount of oil. To get this would require mining or quarrying and elaborate and expensive plants. It is a reserve supply, a possible future resource. It cannot profitably be used today with the present cheap production of petroleum. It belongs to a coming generation, not to ours.

The Ohio shale is a very fine-grained rock and holds its bituminous matter tenaciously. The formation is jointed and a little gas may escape into the cracks and fissures. In northern Ohio[2] wells have sometimes found more sandy layers and obtained gas in sufficient quantity for small local uses. No similar occurrences are known for Delaware County. It may be said that there is very little chance of getting gas in paying quantities from the Ohio shale.

[1]Ashley, G. H., Oil resources of the black shales of the eastern United States, U. S. Geol. Survey Bull. 641 L, p. 319, 1917.

[2]Orton, Edward, The Ohio shale as a source of oil and gas in Ohio, Report of the Geological Survey of Ohio, Vol. 6, pp. 410–442, 1888.

In building the Pennsylvania Railroad's elevated track east of Delaware large quantities of the Ohio shale were used. Children building fires over some of the shale in the side of the embankment ignited the shale which continued to burn for nearly five months in the fall of 1925.

The Sunbury shale is, like the Ohio, a low-grade oil shale. An analysis[1] of a sample from Rocky Fork in northern Franklin County gave 11 gallons of oil to the ton. The thinness of the Sunbury precludes its being an important source of oil at any time.

Soils[2]

Delaware County is an agricultural county; its greatest mineral resource is its soils. The soil is the upper layer of mantle-rock which is capable of supporting plant life. Mantle-rocks and the soils which are derived from them may be classified from the point of view of their origin:

1. Residual soils. These are derived from the decay of the immediately underlying bed-rock. They contain no materials which cannot be found in the bed-rock and generally pass gradually into the bed-rock. There are no residual soils in Delaware County. They are found in Ohio only in the southern and eastern part of the State, beyond the glaciated area. All pre-glacial soils in Delaware County were swept away by the glacier.

2. Transported soils. These have not originated in the place where they now are but have been brought to their present position from a distance by some transporting agent. The soils of Delaware County are all transported soils and of two kinds:

(1) Glacial soils, developed on the glacial boulder-clays of the uplands. These make over $\frac{9}{10}$ of the county surface and give a clay loam.

The glacial soils show variations which are due in part to original differences of accumulation, in part to subsequent changes.

There were accidental differences in the composition of the original till; accidental in the sense that their causes are too complex or remote

[1]Ashley, loc. cit., p. 319.

[2]The following references to general and local works on soils may be useful:
King, F. H., The soil. The Macmillan Co., 1900.
Hopkins, C. G., Soil fertility and permanent agriculture, Ginn & Co., 1910.
Shaler, N. S., Origin and nature of soils, U. S. Geol. Survey, Twelfth Annual Report, pt. 1, pp. 213–345, 1891.
Coffey, Rice, et al. Reconnoissance soil survey of Ohio, Bureau of Soils, Field Operations, 1912.
Lapham and Mooney, Soil survey of the Westerville area, Ohio, Bureau of Soils, 11th Report, 1905, 1906.
Conrey, G. W., Glacial limestone soils of Ohio, Ohio Agricultural Experiment Station, Bi-monthly Bull., Vol. XI, No. 1, Jan.-Feb. 1926, pp. 24–34.

for present explanation. But there was one original difference due to the relation of the till to the bed-rock. In the western half of the county the bed-rock is limestone; in the eastern half, shale. The general direction of the ice was to the southeast. As the till consists in considerable part of local rock (page 90), there is an increasing amount of shaly material in the till as one goes east over the shale of the eastern half of the county.

Immediately after the retreat of the glacier the unaltered top of the boulder-clay was unfit to support plant life, just as today the clay below the present soil zone is unfit for cultivation. The present soil has been prepared by the action of various weathering processes: freezing and thawing, soaking and drying, chemical changes by ground water, burrowing by animals and by plant roots. Since the region was long forested and not grassed, the addition of vegetable material has been by leaf mold, and thus not so abundant or so deep as if it had been a grassed area.

The till at the start contained throughout a considerable amount of limestone, both as stones and as rock flour (page 89), but the ground water has leached the lime carbonate for a distance of several feet down from the surface, so that the local soils in places may even be "acid," poor in lime, and profit by the addition of a certain amount of lime or ground limestone.

The topography varies from flat to rolling. In the flat sections, and these make the larger part of the county, drainage is poor, and subsurface tiling is necessary. Where the surface is rolling, underground circulation is more rapid, and the weathering of the mantle-rock has been deeper and more thorough. This may be offset on certain slopes by the wash of the surface material of ploughed fields to the bottom of the slope.

(2) Alluvial soils, developed on the sands and gravels of the river bottoms. Most of their material is the original stuff of the glacial clays reworked and sorted by the rivers, and they give loamy soils. In the northwestern part of the county, particularly in Radnor Township north of the Broadway moraine, streams under and at the front of the retreating ice margin deposited over the till large amounts of sand and gravel, and here gravelly loams are common. They are found in a few other places in the county where similar conditions held. Indeed the map of the surface deposits of the county serves almost equally well as a soil map.

A soil survey has been made of the Westerville area[1]—the Westerville and Dublin topographic sheets—which includes the southern $\frac{2}{5}$

[1]Lapham, J. E., and Mooney, C. N., Soil survey of the Westerville area, Ohio, U. S. Dept. of Agriculture, Bureau of Soils, Field Operations of the Bureau of Soils, 1905, pp. 5–19, 1906.

of the county, and the results can easily be extended to cover the whole county. Four soil types are distinguished: 1. Miami clay loam, 2. Miami loam, 3. Miami black clay loam, 4. Miami gravelly loam. They are called Miami loams because the type was first described in the Miami Valley, and the term was retained as the work was carried into the central part of the State.

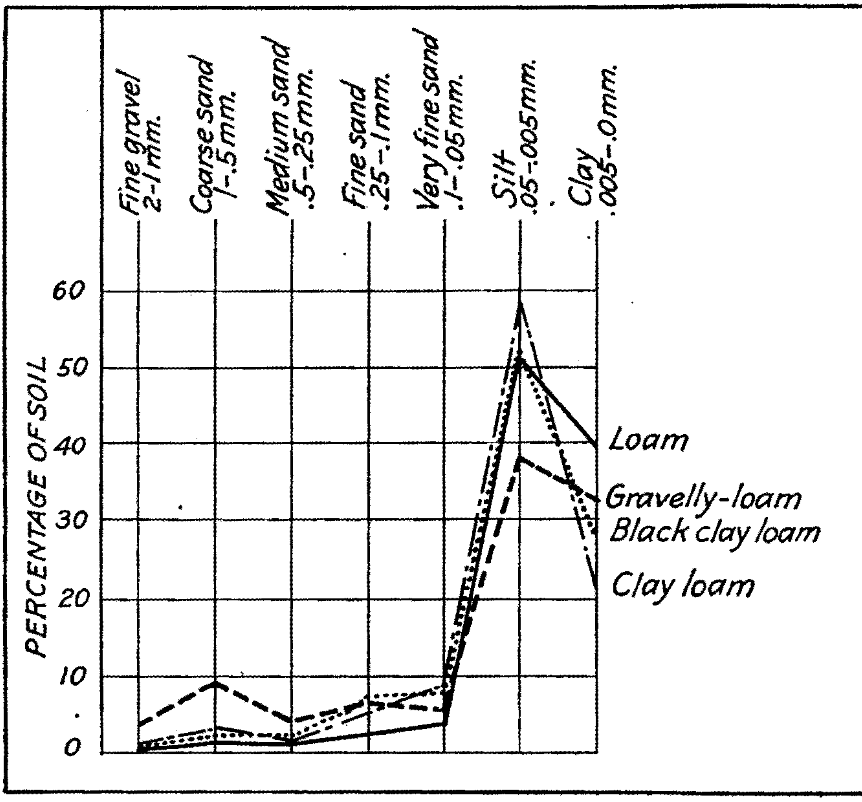

Fig. 28. Mechanical analysis of soil types.

This classification of the Bureau of Soils corresponds very closely with the different kinds of surface deposits shown by the geological map. The Miami clay loam is the soil of the glacial boulder-clay. The black clay loam is the same, as it is found over the lower, flatter, and so wetter parts of the till; it comprises the upland swamp soils. These two types together make up over 93 per cent of the Westerville area; and over 90 per cent of the whole county. The Miami loam includes the ordinary bottom land alluvial soils. The Miami gravelly loam includes two different soils; mainly the gravelly alluvial soils of the higher bottoms, but also the washed and so more stony slopes from the uplands to the valleys, slopes underlain by till.

Figure 28, showing the mechanical composition of the four soil types, is based on the analyses given by Lapham and Mooney and shows a rather uniform mechanical make-up. The differences in the soils seem to be due to slope, relation to water table, and particularly to the more open character of the Miami loams and gravelly loams of the river valleys and their sub-soils.

The mechanical analyses given above omit the stones in the soils. The gravelly loams of the higher bottoms and of the kame and esker hills near Radnor are often abundantly covered with limestone gravel. The stones of the Miami clay loams, the prevailing soil type, are almost wholly crystalline rocks, the ground water having completely dissolved the limestone blocks of the upper foot or two of the till, leaving the insoluble crystallines.

ADDENDA

Note 1

Antevs[1] has determined the rate of ice retreat across New England from Hartford, Conn., to St. Johnsbury, Vt., to be 238 ft. per year and across parts of Canada, 475 ft. Assuming an average rate of 300 ft. per year for central Ohio, it would have taken 440 years for the ice margin to withdraw across the 25 miles separating the Broadway moraine from the St. Lawrence-Ohio divide in northern Marion County.

Note 2

The following partial lists of the flora of the local iron and sulphur springs near Delaware were made by Miss Phyllis Draper:

Iron spring at Delaware Clay quarry:

Algae
- (Diatom) Navicula sp.
- Casmarium sp.
- Cylindrospermum sp.
- Scenedesma sp.

Iron bacteria
- Leptothrix ochracea. Most abundant; practically pure cultures found several times.
- Gallionella ferruginea. Abundant.
- Spirophyllum ferrugineum. Uncommon.

Iron spring at Delaware Springs Sanitarium:

Iron bacteria. Same as preceding spring. Spirophyllum ferrugineum common.

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[1] Antevs, Ernst, Recession of the last ice sheet in New England. Am. Geog. Soc. Research Series No. 11, p. 74. 1922. Also, Retreat of the last ice sheet in eastern Canada. Geological Survey of Canada, Memoir 146, p. 81. 1925.

Iron and sulphur spring at the city dump:

Iron bacteria
- Siderocapsa. On leaf of Populus deltoides.
- Gallionella ferruginea.
- Leptothrix ochracea.
- Spirophyllum ferrugineum.

Sulphur bacteria
- Beggitoa alba.
- Beggitoa sp.

Algae
- Chlamydomonas sp.
- Euglenia grafilis.
- Stigioclonium tenui, var. irregularis.

Sulphur spring at Delaware Springs Sanitarium:

Sulphur bacteria
- Beggitoa alba.
- Beggitoa sp.

Algae
- Oscillatoria sp.
- (Diatom) Navicula sp.

Sulphur spring, Ohio Wesleyan campus:

Sulphur bacteria
- Beggitoa alba. Also in abundance in water from Case's drilled well, Union Street.
- (Diatom) Navicula sp.

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