STATE OF OHIO
DEPARTMENT OF NATURAL RESOURCES
DIVISION OF GEOLOGICAL SURVEY

Information Circular No. 27

DEVONIAN – MISSISSIPPIAN SHALE SEQUENCE IN OHIO

by

Karl V. Hoover

COLUMBUS

1960

STATE OF OHIO

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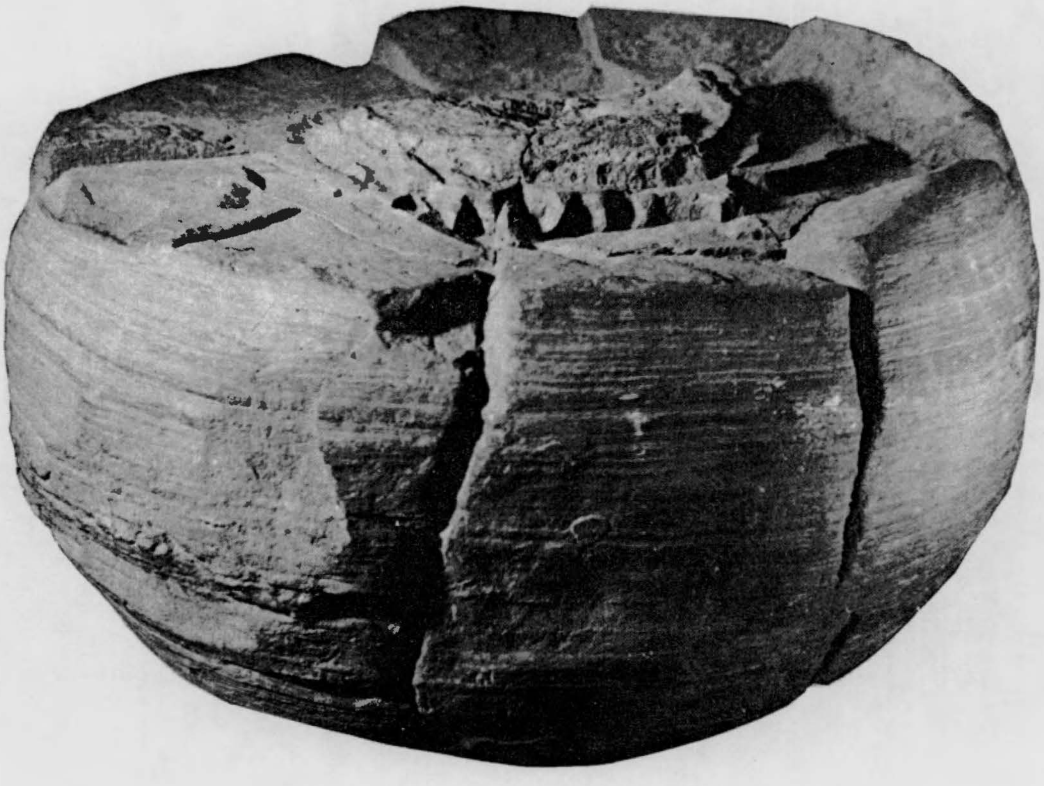

FRONTISPIECE - Typical Ohio shale carbonate concretion showing carbonate core and alternating protuberance around center of the concretion.

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Chapter 1

INTRODUCTION

Rocks of Devonian-Mississippian age in Ohio are among the most important strata in the State. They are the outcropping bedrock or the rock immediately underlying surficial deposits in approximately 25 percent of the counties and are present in some 60 percent of the counties of Ohio.

These rocks have attracted the attention of geologists for more than a century. Though they are transitional between those of the Appalachian geosyncline and the midcontinent cratonic area, the sequence is especially consanguineous to conditions of geosynclinal sedimentation. The lithologic variations are related to facies differentiation of sediments and to the gradual infilling of the basin of deposition.

The description and identification of these rocks have evolved from studies of a local nature in areas where outcrops of limestone, shales, and other economic products have been available. Some regional reconnaissance studies covering states adjacent to and beyond Ohio have demonstrated that many of the Devonian-Mississippian shale units of Ohio can be correlated with those in other States, although they are often known by different names.

Since geological boundaries are independent of state boundaries, there is a need for a uniform classification of Devonian and Mississippian strata that are continuous from state to state. Over a period of years many problems related to continuity, identity, and lithologic variations of the rocks; and to priority and usage of names, have been clarified, until today a reasonable uniformity of nomenclature and classification is possible for the Devonian-Mississippian formations of Ohio.

LOCATION OF AREA

GENERAL

The area covered in this paper includes part of the Central Lowland province to the west and part of the Appalachian Plateau province to the east. The geology is intimately related to the development of the Appalachian geosyncline, and much of its unique and interesting character is due to Ohio's geographic position with respect to the areal spreading of geosynclinal conditions with time. In this area are located some of the final marine geosynclinal facies and their contiguous cratonic facies. Marine sediments showing the effect of terrestrial influences overlie the geosynclinal facies.

OUTCROP AREA

The Devonian-Mississippian shales appear at the surface in three widely separated areas (fig. 1). The most extensive outcrop field crosses the central part of Ohio in a narrow belt from 8 to 20 miles in width, extending roughly north from Adams and Scioto Counties on the Ohio River through the center of the State to Erie County on Lake Erie, and thence eastward along the lake front in an ever-widening pattern into Pennsylvania. The dip of the rock in central Ohio is toward the southeast, averaging about 35 feet per mile. Passing northward and northeastward the dip changes more and more toward the south and finally becomes southwestward in northwestern Pennsylvania.

A second area of outcrop, much smaller in extent, occurs as an outlier just a little east of the crest of the Cincinnati arch. This is the Bellefontaine outlier, approximately 40 miles northwest of Columbus, Ohio. The outlier is an elliptical elevated area of about 130 square miles, which extends from the northern part of Logan County south to the village of Cable in Champaign County.

A third region of Devonian-Mississippian shales, largely buried by drift, is present in the northwestern part of Ohio, west of the Cincinnati arch. This crescent-shaped belt of outcrop extends southward from Michigan into Lucas and Henry Counties, and thence westward in the vicinity of Antwerp, Paulding County, where it passes into Indiana. The dip of the strata is northwestward toward the concavity of this crescent-shaped outcrop pattern.

SUBSURFACE AREA

Most of the area of the Devonian-Mississippian shales lies beneath the surface; therefore, it is necessary to draw heavily upon the information gleaned from subsurface data for geologic knowledge of these shales. In addition to wells which strike these shales near their outcrop areas, there are a large number of wells which penetrate them both east of the main outcrop area and in the northwestern part of the State.

SCOPE AND PURPOSE OF PRESENT STUDY

Although much has been written concerning the Devonian-Mississippian shale sequence of Ohio, there is still confusion regarding the exact correlation of units in distant parts of the State with those in the type sections of the units. A vast amount of the voluminous literature concerning these rocks is based upon studies of earlier workers, rapid reconnaissance surveys, and extrapolations from adjacent areas.

It is felt that the misunderstanding in correlation is due largely to the lack of a connected study of the shale sequence over its entire area of deposition. Practically all studies dealing with these shales have been concerned with restricted areas or have been reconnaissance studies. Geologists have disagreed with the classifications of previous workers, each having apparently based his subdivisions on different criteria. All of this resulted in considerable confusion in later studies.

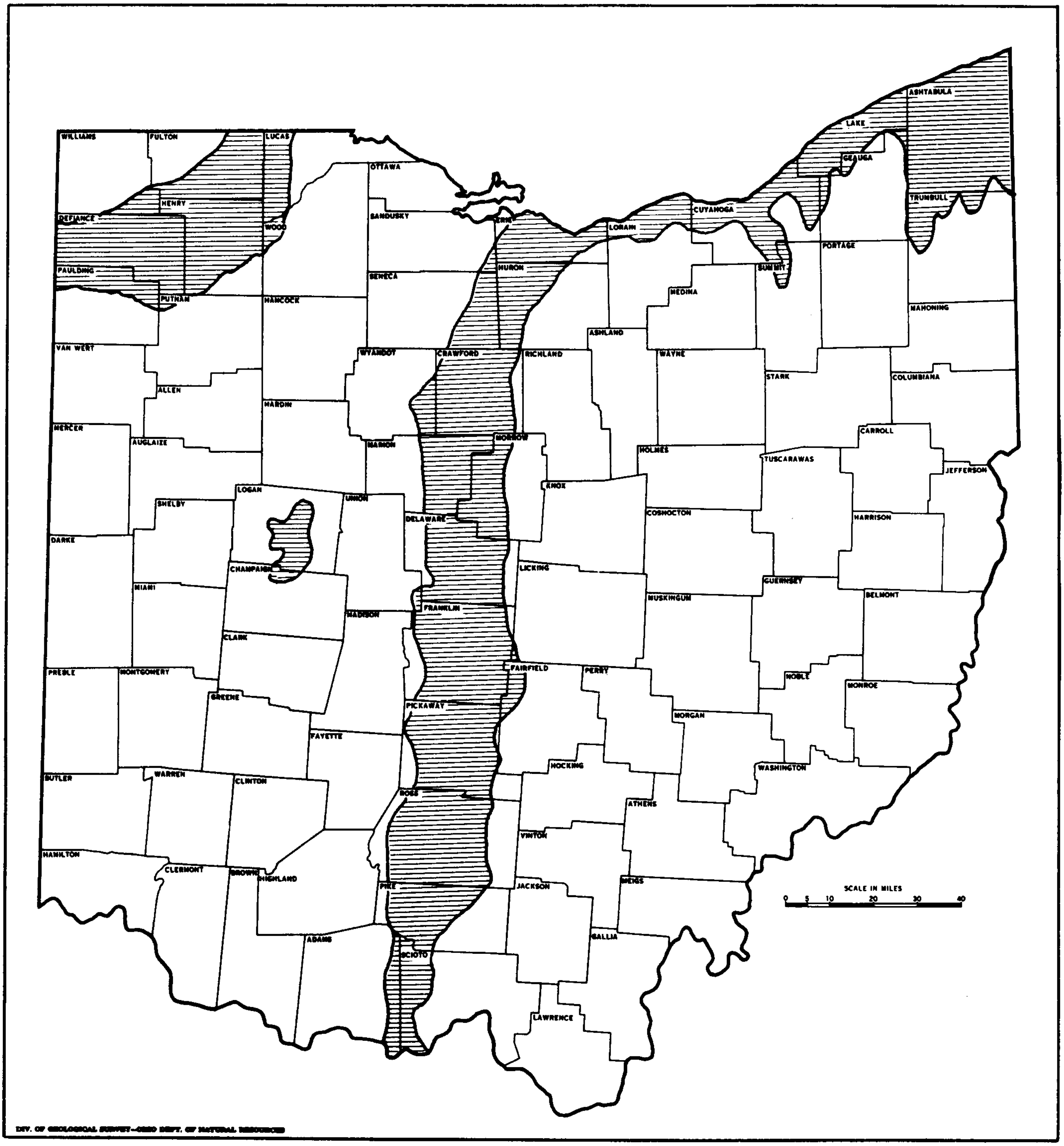


Figure 1. - Outcrop area of the Devonian-Mississippian shales.

Although the conodonts have been studied regionally in considerable detail by W. Hass (1947), the remainder of the fauna unfortunately has been neglected. Some regional work, as yet unpublished, has been done by J. Schopf and M. Winslow, of the U. S. Geological Survey, on the microflora of portions of this sequence. Fossils are only locally abundant, but careful search usually uncovers a fauna of surprising size. Lingulae, for example, are profusely abundant in certain areas, although because of their great stratigraphic range, they are, except in a general way, of little value in correlation.

Few writers have attempted to present a picture of the geologic setting, or to expound upon the geologic history of this area during late Devonian-early Mississippian time. In more recent years geologists have come to realize that such studies, giving more detailed information as to paleogeography, sources of sediments, etc., are necessary for a complete understanding of the rock formations.

Mineralogical studies have been virtually nil, though Nelson (1955) uses clay-mineralogy studies of this shale sequence of northern Ohio to great advantage in evolving his concepts of facies correlations. Petrographically such studies have been practically a stepchild in the study of Ohio geology. The black shales have been considered for their economic value in several research programs, but with generally negative results. However, with future advances in technology such constituents as uranium, thorium, and oil may make these shales economically exploitable.

With the above shortcomings in mind, the present study was undertaken in the hope that through a careful evaluation of both the lithological and the faunal literature of the Devonian-Mississippian shale sequence, a more thorough understanding of the formations in question would result. Also, the presentation of the shortcomings in our knowledge concerning these shales may stimulate research programs through which data may be assembled to answer many questions.

There may seem to be considerable repetition of certain points to the person who reads this report straight through. This has been provided deliberately for those using the work as a text. The author has so designed the report that a person can use any section as a unit; thus certain points must be made in several contexts. The following list gives a few projects that might be pursued to advance the knowledge of the Devonian-Mississippian shale sequence:

1. Lithologic and paleontologic study of the Olentangy shale in the type area and comparison with the named shales and limestones tentatively correlated with it.

2. Systematic paleontologic study of the Devonian-Mississippian shale sequence.

3. Mineralogical, petrographic, physical, and chemical studies of the Devonian-Mississippian shale sequence.

4. Study of the association between uranium and other mineral constituents of the Ohio shale.

5. Study of the problem of the Chagrin shale pinchout.

6. Study of the problem of the environment of deposition of the Ohio shale.

7. Establishment of the stratigraphic limit of the Devonian system.

8. Study of the overlapping and (or) facies relationships of the various named Ohio shale units.

9. Regional stratigraphic correlation of the Devonian-Mississippian shale sequence.

10. Comparative study of the sandstone of the Bedford shale and Berea sandstone by petrographic methods.

Chapter 2

RÉSUMÉ OF GEOLOGY AND STRATIGRAPHY

DEFINITION, DISTRIBUTION, AND DELIMITATIONS

The Devonian-Mississippian rock sequence described in this paper consists of highly argillaceous shales and siltstones. The term "shale" is in common use for mudstones that are fissile or have the property of splitting readily into layers. Shales represent aggregates of fine-grained mineral particles which, during deposition or through subsequent pressure, have taken on a lamination which permits them to be split into thin layers. The aggregates, in the case of several of the units discussed here, are broken down with difficulty so that they are only moderately plastic after fine grinding or long weathering. Many are weakly plastic and require the addition of plastic clay to make them workable.

This thick sequence of shales and siltstones is generally assigned in part to the Devonian system and in part to the Mississippian system. These shales have been given formational status by many workers, partly on the basis of their faunal content, but mostly on the basis of their lithologic character. However, there have been many disagreements concerning the position of the contacts between these formations, and in regional correlations it is presently impossible to determine the contacts. Not only do these shales grade laterally into one another, but there is usually a transitional zone between the named formations.

In this paper, the shale series will be referred to simply as the Devonian-Mississippian shale sequence. The reason for this is that by definition a formation must be a mappable unit with areal extent. It is felt that, since the individual units of these shales are presently not mappable, they should not possess formational status. Therefore, the individual formational names assigned to this sequence have been used to refer generally to the shale unit possessing the attributes assigned to it, without any attempt to set limits to its vertical range. Those units which readily lend themselves to subdivision (at least locally) are referred to as members. This results in retaining for the most part the nomenclature as it is now understood by the geologist.

In northern Ohio, the Ohio shale is regarded as consisting of three members - in stratigraphic order, the Huron, the Chagrin, and the Cleveland. The Cleveland shale member is considered by some writers to have a "member" called the Olmsted. Stratigraphically the Cleveland shale is conceded by all investigators to be the top member of the Ohio shale. The stratigraphic position of the other two members has been disputed, some researchers regarding the Huron as the basal member and others the Chagrin.

Some workers have considered the Ohio shale as a facies deposit. Nelson (1955) has concluded from his mineralogical and stratigraphic studies of the pre-Berea age sedimentary rocks exposed in northern Ohio that the different lithologic expressions of rocks occupying the Chagrin, Cleveland, and Bedford zones should be redefined in terms of facies elements.

In the central and southern Ohio outcrop region the middle gray unit, the Chagrin shale, is either missing or so ill-defined that here the black shales are normally referred to as just the Ohio shale. Though the author accepts this concensus of opinion, some attempt has been made in the lithologic consideration of this paper to extend the concept of the Ohio shale members to the full extent of the State. Many evidences upon which the members in northern Ohio are defined extend into central and southern Ohio. Notable among these evidences are cone-in-cone structures of the Cleveland shale member, calcareous concretions of the Huron member, and conodont zones that distinguish the units (Hass, 1947, p. 133). However, for all practical purposes the black shales of central and southern Ohio should not be split lithologically into members, although Hass (1947), for example, feels that faunal evidence indicates that a sedimentary break occurs at what conceivably is the contact between the Huron and Cleveland shales in this region.

STRATIGRAPHY

In western Ohio the Cincinnati arch brings to the surface the Columbus and Delaware limestones, which presently are correlated with the Onondaga limestone and Hamilton beds of New York. The limestones occur at successively lower elevations eastward, and in the subsurface these limestones are grouped as "Onondaga" (Personal communication, G. G. Shearrow, Ohio Division of Geological Survey). Figure 2 is a generalized columnar section of the rock sequence reviewed here with its associated formations.

Carbonate rocks underlie the shale sequence in all outcrop regions, except locally in the extreme southwestern outcrop area. Here, presumably, the Olentangy portion of the shale sequence is missing, and the Ohio shale rests upon the Hillsboro sandstone. The cap rock for this shale sequence east of the Cincinnati arch is the Berea sandstone. Throughout much of the outcrop and subsurface area this relationship is represented by an unconformable contact. In southern Ohio, however, the Bedford and Berea intervals are so lithologically similar that a recognizable contact cannot be drawn. In northwestern Ohio, neither the Bedford nor the Berea is mappable. Here the Mississippian section is mapped simply as Waverly (Bownocker, 1920) or as Bedford-Berea (undifferentiated).

The subdivision of Devonian-Mississippian shales of Ohio is based on the lithologic character of the shales. It is fortunate, therefore, that the outcrop belt, although on the whole rather poor in exposures, contains some well-exposed sections from which the divisions discussed here are defined. The stratigraphic column falls into rather natural divisions, each characterized by lithologic features of diagnostic value. This makes it possible to work out the general sequence of beds. For purposes of description the series has been divided into five divisions. Although these divisions are well-individualized units, the precise horizons of the division planes separating them are matters for somewhat arbitrary decision. Contiguous units usually grade one into another, though locally they all succeed one another disconformably. In the following lithologic descriptions the criteria by which the planes of separation are fixed will be set forth as clearly as possible, with emphasis on the distinctive characteristics of each stratigraphic unit. The brief descriptions of the divisions, in the order of the generally accepted stratigraphic position, are intended to give the reader a general concept of the character of the rocks of the Devonian-Mississippian shale series in Ohio, and to lay a foundation for any attempt at broad correlation with the formations of other regions.

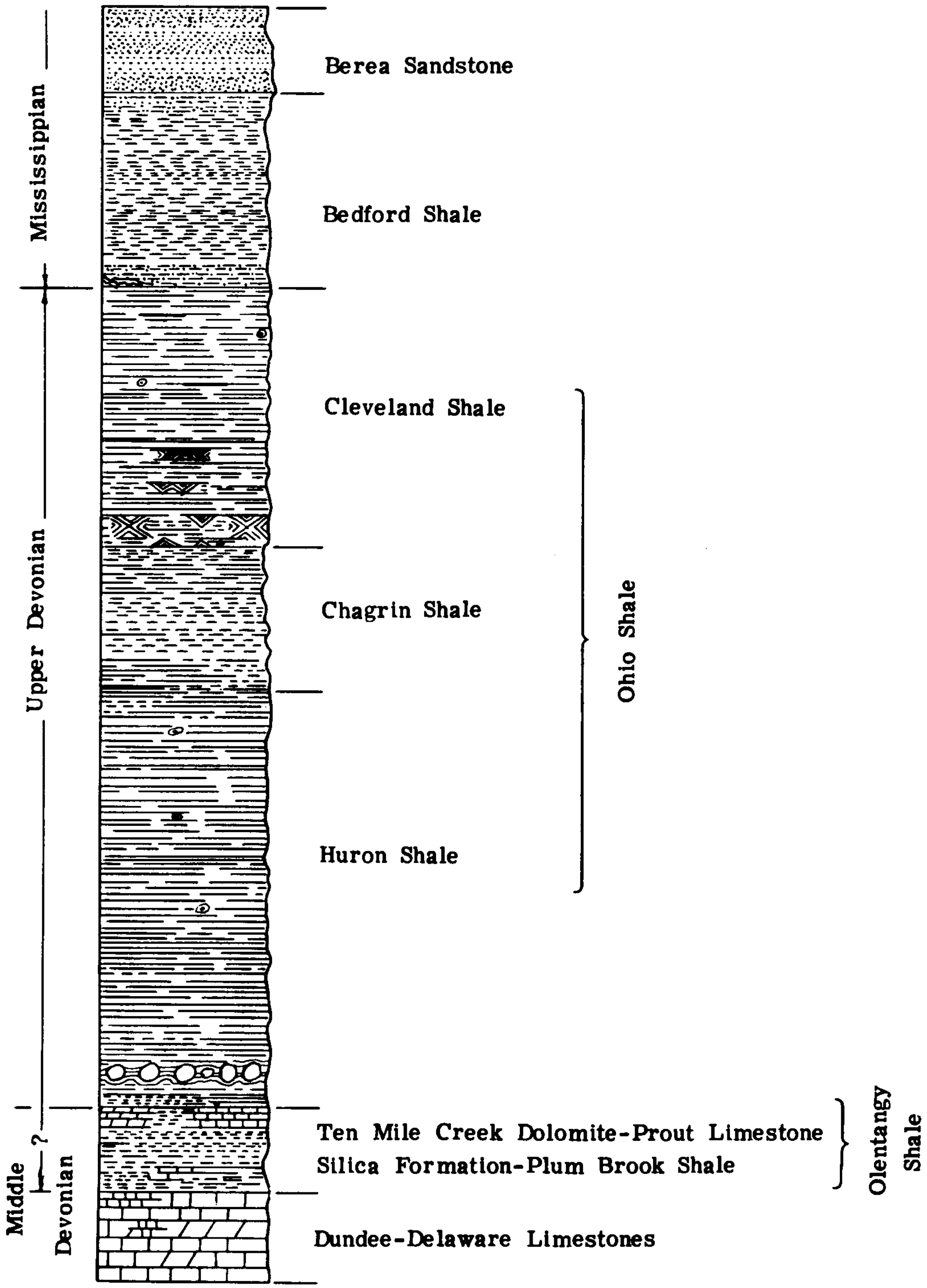


Figure 2. — Generalized columnar section of the Devonian-Mississippian shale sequence.

Definition

Winchell (1874, p. 284) was the first to use the name "Olentangy shale" for the mass of bluish-gray shale underlying the Ohio shale. This blue-gray shale previously had been referred to as the equivalent of the Hamilton shale of New York, though its age could not be substantiated by diagnostic Hamilton fossils. Because of the seemingly unfossiliferous character of the shale, Winchell did not extend the use of the term "Olentangy shale" outside the confines of Delaware and Franklin Counties. However, paleontological collection over a period of years has yielded a reasonable number of megascopic fossil species and numerous microscopic species.

The definition of the Olentangy shale is a twofold problem, involving both age and regional stratigraphic relationships. Stratigraphically it is problematic whether the gray-blue shales of southern Ohio are the same as the Olentangy of central Ohio and whether the central Ohio Olentangy is continuous through northern Ohio into Ontario, Canada, as well as northwest across the Cincinnati arch into northwestern Ohio (pl. 1). It is difficult to identify the Olentangy in southern Ohio due to the local absence of the typical Olentangy rock type. Also, the compact beds or concretionary masses of blue limestone which characterize the Olentangy in central Ohio are missing. Detailed work by Lamborn (1927) led him to conclude that in southern Ohio the Olentangy shale: (1) is local in its occurrence, (2) rests disconformably on the Silurian limestones, and (3) lies conformably below the Ohio shale.

Several schools of thought prevail concerning the existence of the Olentangy shale in northern and northwestern Ohio and, if it is present, its stratigraphic position. This difference of opinion arises from the fact that a shale unit and limestone unit lie between the Huron shale and the Delaware limestone of northern Ohio (or Dundee limestone of northwestern Ohio) and so hold generally the position occupied by the Olentangy in central Ohio. The limestone in the northern part of the State was referred to under the name of Prout limestone by Prosser (1903, p. 47), but Stauffer (1907, p. 592) is credited with giving the name a formational status. This limestone is described as immediately underlying the Huron (Ohio) shale. Stauffer assigned a Hamilton age to the Prout and generally supposed it to be the northern equivalent of the Olentangy shale. Subjacent to this limestone is a soft gray shale containing thin bands of argillaceous limestone, first described by Orton (1893, p. 20) as cropping out in the Prout Station section. Grabau (1917) assigned the name "Plum Creek shale" to this unit, but subsequently the name has been changed to Plum Brook shale (Cooper, 1941, p. 181).

The names "Silica formation" and "Ten Mile Creek dolomite" are assigned to the disputed shale unit and carbonate unit, respectively, in northwestern Ohio. The shale unit was named the Silica formation by Ehlers and others (1951, p. 8). The overlying carbonate unit was named the Ten Mile Creek dolomite by J. E. Carman for exposures along Ten Mile Creek, Lucas County, Ohio.

The problem of correlation revolves around the relationship of the Olentangy in central Ohio to the Prout limestone-Plum Brook shale of northern Ohio and the Silica shale-Ten Mile Creek dolomite of northwestern Ohio. This stratigraphic problem involves not only the lithologic association but also the age relationship. At various times and by different authors, but notably by Stauffer (1916, 1938, 1938a), the Plum Brook shale has been correlated with the Olentangy, and the so-called Prout limestone has been regarded simply as a member of the Olentangy shale.

Many workers (Winchell, 1874, p. 287-89; Grabau, 1917; Lamborn, 1927; Westgate, 1926, p. 31-37) have suggested that the Olentangy is the basal phase of the Ohio (Huron) shale and either is not represented in northern Ohio or, if present, rests disconformably on the

Prout limestone and on higher Middle Devonian limestones in Canada. If either of these suggestions is true, then the so-called Prout limestone and Plum Brook shale should not be correlated with the Olentangy, and they can be awarded formational status. Later investigators (Stumm, 1942; Cooper, 1933; Stewart, 1927, 1936, 1938, 1955; Stewart and Hendrix, 1939, 1945, 1945a), relying more upon the evidence presented by the study of microfossils than upon that of macrofossils, have failed to rule out unequivocally the direct correlation of the central Ohio Olentangy with these northern and northwestern units; but their investigations also strongly suggest that the fossil assemblages are dissimilar enough to set the Olentangy shale aside as distinct from those units in northern and northwestern Ohio. They conclude that the Plum Brook shale, Prout limestone, Silica shale, and Ten Mile Creek dolomite are more closely allied with each other and with Hamilton rocks of Canada and New York than with the central Ohio Olentangy shale. Cooper and others (1942, p. 1774) report concerning the Olentangy shale that "... the presence of the Tully coral Lopholasma at the base of this shale [indicates] at least a partial representation of the Tully." With our present knowledge, therefore, the Olentangy shale of central and southern Ohio must be considered younger than the formations occupying the same stratigraphic position in the northern and northwestern portions of Ohio. Tentatively, then, the Olentangy proper is upper Devonian and the "stratigraphic" equivalent rock to the north is middle Devonian in age.

One aspect of the problem yet to be considered is the contiguous (or noncontiguous) relationships of these rocks. Stauffer (1916, p. 476-487) correlated the Olentangy shale of central Ohio with the Plum Brook shale and Prout limestone of northern Ohio and the blue-gray Hamilton shale in Canada. However, he pointed out an apparent unconformity between the Olentangy and the overlying Ohio shale. He (1916, p. 485) reported a stratigraphic interval of 150 feet from the top of the Encrinal (Prout) limestone to the base of the Devonian (Kettle Point or Huron) shale at Kettle Point, Ontario. In tracing this interval southward into Ohio, Stauffer found the rocks representing this interval wanting. He (1916, p. 485-487) wrote:

> The Huron... lies directly upon the Prout limestone at Sandusky. It therefore either represents the upper Hamilton shale and limestone of Ontario or these deposits are wanting in northern Ohio and the Huron shale rests unconformably on the Encrinal limestone... Kindle has correlated the black shale at Kettle Point, Ontario, with the Huron shale of northern Ohio. If this correlation is correct, as seems probable, the Huron shale does not represent the Upper Hamilton, but rests unconformably on the Prout or Encrinal limestone.
>
> [Southward in Crawford and adjacent counties drill records record the absence of the Prout limestone and locally the absence of the Olentangy shale. Where the Olentangy is absent, the Huron rests directly on the Delaware limestone.] At "Dripping Rock"... the contact between it [the Olentangy] and the overlying Ohio shale is most marked and slightly undulating... Near the Ohio River... the Ohio extends down to the Silurian limestone and is firmly welded to it.
>
> Southward from Kettle Point, Ontario, therefore, the Huron or lower portion of the Ohio shale rests on older beds to which its relationship must be that of unconformity (disconformity). This relationship is not strikingly perceptible at any one place, but in southern Ohio the time interval between Silurian and Devonian strata, which are in contact, is enormous.

During field studies in Delaware County, Grabau found substantiating evidence for Stauffer's proposed disconformity between the Olentangy and Huron shales. Though in all the sections studied thin bands of black shale alternating with gray shales indicative of lithologic transition were noted, he (Grabau, 1917, p. 339-40) wrote concerning this diastem as follows:

> At the contact with the first great mass of Huron shale there are sometimes found indications of a slight drying of the surface of the Olentangy, with the

> cakes or scales of dry, gray mud, which were then incorporated in the black mud. This is just what we should expect if the deposition of the gray muds had come to an end and sedimentation were renewed by the influx of the black mud from another source. Essentially, however, deposition here was continuous, and after the commencement of the sedimentation of the black Huron mud, there was a temporary recurrence of gray sedimentation, so that we see today a 10-foot bed with all characters of the typical Olentangy lying above a considerable thickness of black Huron shale. In both the upper and lower part of this interbedded mass of Olentangy occur thin bands of black shale, as they do in the typical Olentangy lower down.

The 10-foot bed of gray shale to which Grabau makes reference no doubt should be correlated with Chagrin shale rather than with Olentangy. Grabau (1917, p. 340-341, 343) regards the Olentangy as a basal facies of the Ohio shale because of the interbedding and the conformable relations of these two rock types in central Ohio. He believes (1) that the Olentangy shale is a lentil which "pinches out" to the north, and (2) that in Ohio and adjacent states there is a great hiatus between the upper Devonian shales and the underlying formations.

Westgate (1926, p. 33-37) has demonstrated the presence of a transitional zone between the Olentangy and Ohio shales of Delaware County in which the two lithologic types alternate and interfinger with each other. He reviewed Stauffer's and Grabau's concepts, and on the basis of his field evidence, agreed with Grabau's interpretation that there is an unconformity at the base of the Olentangy.

In southern Ohio the lower portion of the Ohio shale is so interbedded with blue shale that the contact between the Ohio and Olentangy shales can not be distinguished with certainty. Lamborn (1927; 1929) showed that this blue shale and the Ohio shale in southern Ohio are the results of continuous deposition; that the blue shale rests on the Delaware limestone at Delaware, Ohio; and that to the south the Olentangy rests on successively older Devonian and Silurian formations. Lamborn concludes that the blue shale in southern Ohio is the Olentangy, and he concurs with Grabau's interpretation that the Olentangy rests unconformably on the underlying limestones.

All subsequent field studies have failed to demonstrate a depositional hiatus between the Ohio and the Olentangy shales as propounded by Stauffer. The investigations wrought by the paleostratigraphers and paleontologists have not been concerned with the presence of an unconformity between the Olentangy and the Ohio shales. But, if the faunal relationships are diagnostic of cessation of deposition or of noncontiguous sedimentary basins, their writings suggest nongenetic relationships between the various "Olentangy" lithologic entities.

If the carbonate, argillaceous, and clastic ratios are plotted for the stratigraphic interval concerned here, from north to south, it becomes apparent that the argillaceous content increases at the expense of the carbonate. In the north this interval is recognized by the presence of good limestone beds alternating with blue shale beds plus a comparatively thick and presumably mappable Prout limestone unit. To the south the Prout limestone drops out and the individual limestone beds become more argillaceous. Finally, at the Ohio River, carbonate content is not detectable by field methods. Such evidence suggests a facies relationship for this interval, both vertically and laterally.

Dating these rocks in the three geographic regions of Ohio under consideration remains a controversial matter. It is here suggested that the Olentangy, Plum Brook shale, Prout limestone, Silica shale, and Ten Mile Creek dolomite are stratigraphically correlatable, with the reservation that the Olentangy is probably upper Devonian in age as suggested by Stewart (1955, p. 155, table 3).

The top limit of the Olentangy shale in central and southern Ohio is considered to be the uppermost gray shale bed in contact with a black shale layer. In the area of Prout limestone and Ten Mile Creek dolomite outcrop, the contact between them and the overlying black shale presents no problem. A disconformable relationship exists between the underlying older formations and the base of the Olentangy shale.

Character

The Olentangy of central Ohio is chiefly a bluish-gray to greenish-gray clay shale with black fissile shale beds in the upper portion. It is characterized by flat concretionary masses of blue limestone; compact blue limestone layers; and pyrite in the form of small nodular concretions, small grains or crystals, and in disseminated form.

The Olentangy is a soft nonlaminated clay shale which crumbles easily upon slight to moderate weathering. When the mass crumbles, it first tends to break up into small lens-shaped pieces which finally soften and pass into a blue clay (fig. 3). Calcareous concretions

Figure 3. - Typical exposure of weathered Olentangy shale at the Narrows on the Olentangy River, Franklin County, Ohio. Note the projection of the more weather-resistant highly siliceous fissile Ohio shale.

are present in considerable numbers and are generally disc-shaped (oblate) spheroids. Some are 2 feet long and 1 foot thick, but most are much smaller. The Olentangy concretions never attain the size reached by the Huron shale concretions, though the mineralogical and organic constituents are comparable. The Olentangy concretions are diagnostically less regular in shape than those of the Huron. Measured sections reveal that the limestone lenses and layers are distributed throughout the shale but are more numerous in the basal portion.

The Olentangy is not considered a fossiliferous shale, though a dozen or so megascopic species are represented, and examination of the shale by microscopic aids has revealed a much more impressive microscopic fauna. Continued efforts of the micropaleontologist may eventually reveal a florula and faunule which will distinguish it from the units with which it is now allied.

Westgate, in his report on Delaware County, included a section on the microscopic study of the Olentangy shale by W. J. McCaughey. The microscopic characteristics of the shale were described in this report as follows (Westgate, 1926, p. 32-33):

> 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 percent 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.

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.

The Olentangy of southern Ohio is characterized by Lamborn (1929, p. 38) as follows:

> ... The lithological characteristics and the general stratigraphic relation of this blue shale to the overlying black Ohio shale are similar to those of the Olentangy shale of central Ohio, although the zones of black shale interstratified with the blue shale become more numerous and thicker in southern Ohio, so that in some localities it is impossible to draw a sharp line of separation on lithological grounds.

Concerning the carbonate content of the southern Ohio Olentangy shale Lamborn (1927, p. 716) has written:

> ... Throughout the northern part of the area under consideration a characteristic feature of the Olentangy formation is the presence of thin layers of compact blue limestone or concretionary masses of blue limestone arranged in definite zones or distributed irregularly throughout the shale. Limestone of this nature occurs as far south as Bainbridge, but is wanting in localities farther to the south. The limestone, together with the associated shale is fossiliferous in the Delaware and Sandusky regions, although no fossils have been found in localities south of Columbus.

In northern Delaware County the Olentangy disappears beneath the glacial drift. Devonian rocks next crop out in Huron County to the north or Lucas County to the northwest. Undisputed Olentangy shale is not present in these areas; rather the Olentangy stratigraphic interval is represented by the Prout limestone and Plum Brook shale (northern Ohio) or Silica shale and Ten Mile Creek dolomite (northwestern Ohio).

The Plum Brook shale is a soft gray shale with interbedded bands of argillaceous limestone. It is generally abundantly fossiliferous. The Plum Brook fauna is similar to the upper Silica fauna.

The Prout limestone is a hard siliceous generally gray to brown limestone. Beds of light cherty bluish to yellowish marly limestone are common. The Prout limestone is very susceptible to solution action. Therefore, in outcrop exposures and core sections this limestone is honeycombed, with the more siliceous portions remaining in relief (fig. 4). It is quite fossiliferous. The fauna is regarded as Hamilton in age and consists mostly of poorly

Figure 4. - Outcrop of Prout limestone, along the relocated Baltimore and Ohio Railroad tracks west of Prout, Ohio.

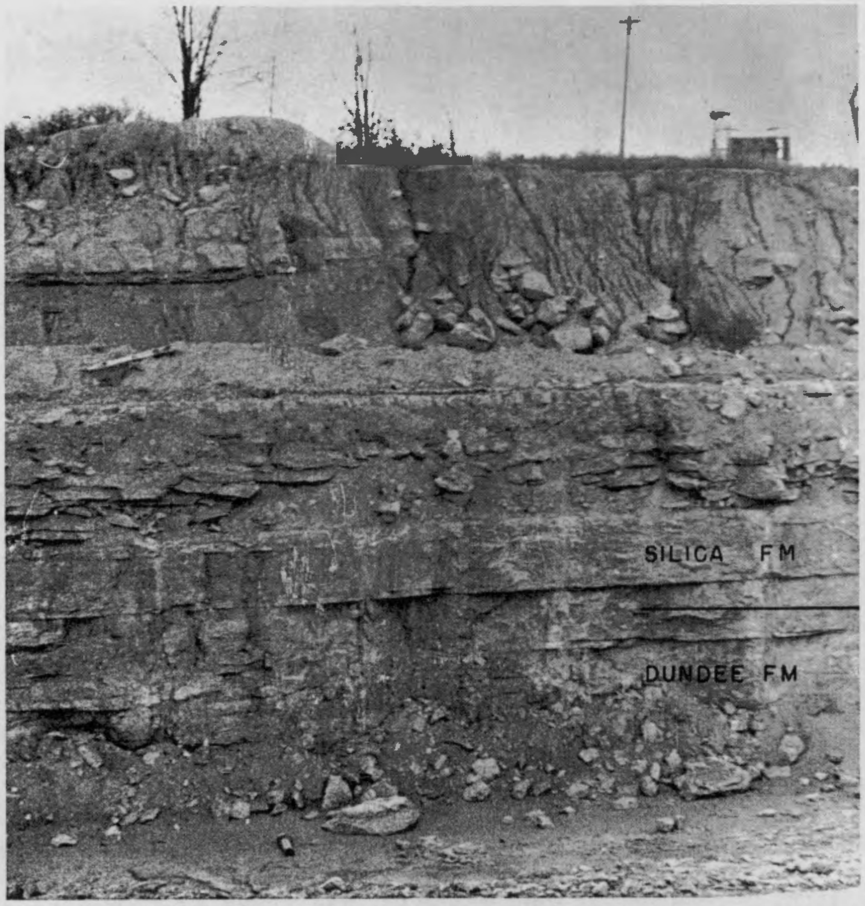


Figure 5. - Typical exposure of the Silica formation, near Silica, Ohio.

preserved corals, brachiopods, and crinoid stems.

The Silica formation is a series of alternating shales and limestones that are highly fossiliferous and are thin to thick bedded (fig. 5). The shales are bluish gray, highly calcareous, and soft, and weather very rapidly upon exposure. They contain much iron sulfide in the form of marcasite concretions, pyritized fossils, and disseminated pyrite grains and crystals. Limestone beds are more abundant at the bottom and top. The basal limestone beds are the bluish-gray argillaceous crystalline and fossiliferous limestone given the provisional name "Blue" limestone by J. E. Carman (Bassett, 1935, p. 437). The prominent limestone beds at the top are similar to those alternating with the shale beds in the middle portion of the unit. They are highly fossiliferous, light to dark gray, and argillaceous.

Overlying the Silica formation in northwestern Ohio is the Ten Mile Creek dolomite. Faunally, it shows affinity with the Prout limestone of northern Ohio. Field relationships between the limestone beds of the Silica formation and the Ten Mile Creek dolomite are similar. Both are bluish gray, argillaceous to crystalline, and thin to massive bedded. The distinguishing features seem to be that the Ten Mile Creek dolomite is predominantly a dolomite and is not as fossiliferous as the limestone beds of the Silica formation.

Thickness

The undisputed Olentangy shale is variable in thickness and in some places is absent. The Olentangy in the type area averages 28 feet in thickness. In southern Ohio the thickness ranges from 0 to 58 feet. The variation in thickness can be accounted for by the filling in of Olentangy sediments in any irregularities on the seafloor, and by discrepancies in location of the Olentangy-Ohio contact by various workers.

Eastward from the outcrop the subsurface investigators have not made a concerted effort to distinguish the Olentangy from the overlying Ohio shale. Any attempt to determine the thickness by subsurface methods no doubt will indicate as much variation in thickness of the formations as is shown in measured sections.

Regional information regarding the thickness of the Plum Brook shale-Prout limestone or Silica formation-Ten Mile Creek dolomite has not been worked out. Thickness data for these units are limited generally to their areas of outcrop. Until data pertaining to the lateral and vertical extent of these units are collected, the regional thickness can not be described. Stumm (1942, p. 554) reports 36 feet as the combined thickness of the Plum Brook shale and Prout limestone in its area of outcrop in Erie County. Eastward this interval is represented by the Plum Brook shale, which has been reported to be 142 feet thick by Rector (1950, p. 7). Ehlers and others (1951, p. 20-21) report 93 feet as the combined thickness of the Silica formation and Ten Mile Creek dolomite in the Lucas County exposures.

Distribution

Typical Olentangy shale has been recognized in the outcrop from the Ohio River northward through Adams, Pike, Ross, Pickaway, Franklin, and into Delaware Counties. However, it is not present in some stratigraphic sections measured by Lamborn (1927; 1929) in some of these counties. In northern Delaware County it is covered by glacial drift. Undisputed Olentangy shale has not been found in the more northern counties, and eastward the subsurface stratigraphers have not always recognized the formation.

The Plum Brook shale crops out in Erie County and has been logged in the subsurface eastward in Ashtabula County by Rector (1950, p. 7-9, 26-27). Its southward extension has not been traced, due to lack of outcrops.

The geographic distribution of the Prout limestone is not known. Stumm (1942) has described the Prout limestone in its Erie County outcrop area. Rector (1950, p. 26), who studied the core recovered from a well drilled for salt tests in Ashtabula County, reports:

> A limestone that could be considered equivalent to the Prout limestone of north-central Ohio, was not found in the core.
>
> The Plum Brook shale is in apparent conformable contact with the overlying Huron shale.

Due to the thick glacial drift the bedrock surface in northwestern Ohio is exposed only along a few streams. Most of our knowledge of the Silica formation and Ten Mile Creek dolomite has resulted from studies made in commercial rock quarries. Little is known concerning the geographical distribution of these units. Ehlers and others (1951, map 1) have mapped these units as the sole representatives of the Traverse group in northwestern Ohio and southeastern Michigan. Their map shows the Traverse group forming an "S"-shaped pattern. The middle portion extends away from the Ohio-Michigan boundary as a narrow, constricted north-south striking pattern. The top and bottom of this "S" widen in outline away from the constricted middle.

HURON SHALE

Definition

The portion of the Ohio shale referred to as the Huron shale was named by Newberry (1871, p. 19) who stated that "its outcrop forms a belt from ten to twenty miles in width, reaching from the Lake shore at the mouth of the Huron River, almost directly south to the mouth of the Scioto." Its outcrop on the shore of Lake Erie was given as extending from east of Sandusky to Avon Point. The cliffs north of Norwalk, Ohio, along the Huron River were designated the type locality. The Huron member is characterized by carbonate concretions or septarian nodules generally from 1 to 6 feet in diameter, but as large as 15 feet.

The Huron and Cleveland members of the Ohio shale are for the most part lithologically identical. The base of the Huron is taken as the black shale bed resting upon the highest most gray shale (or limestone) bed of the underlying formation or unit, which in different regions is the Plum Brook shale, Prout limestone, Ten Mile Creek dolomite, Olentangy shale, or, locally, Silurian or Devonian limestone. The upper limit is defined as the uppermost black shale in the area where the gray arenaceous Chagrin shale is present, or as the top of the uppermost layer of carbonate concretions, or the base of the lowermost cone-in-cone structure, if these are observable. Such an arbitrarily placed boundary leaves much to be desired. It is predicated on the assumption that either the cone-in-cone limestone or the carbonate concretions will be observable in any one outcrop in close enough proximity to indicate the boundary.

No divisions have been established in the Huron shale. It is generally supposed that the shale that Newberry termed "Huron shale" comprises all of the black shale which Andrews, later in the same report, named the "Ohio black shale." Newberry's Huron shale represented only the lower mass of black shale which occurs in the northern part of the State. Presently the top of the Ohio shale in southern Ohio is considered as corresponding to the top of the Cleveland shale. Andrew's Ohio shale is regarded as equivalent to Newberry's Huron, Chagrin, and Cleveland shales of northern Ohio. Hass (1947, p. 133-134) has found from the study of conodonts that certain genera and species are common only to the Huron shale (zone). These same conodonts are mutually present in south-central Ohio as well as in the northern part of the State. To prevent confusion with existing literature, Hass has found it more convenient to refer to the "Huron shale" of central and southern Ohio as the lower Ohio shale zone.

Character

The Huron and Cleveland shales are lithologically alike in all their apparent characteristics. The Huron shale is distinguished from the Cleveland shale by its large calcareous concretions, which are very conspicuous. Frequently these concretions are formed about fish fragments, plant material, or some other organic nucleus.

Though the Huron shale, like the Cleveland shale, is characteristically grayish black and fissile, it is not homogeneous black shale, for it has some gray argillaceous layers and thin sheets of micaceous, pearly sandstone interstratified with the more carbonaceous portions. The beds of black carbonaceous shale are separated by thin laminae of carbonate and quartz. The fresh shale is bluish black and grayish black to brownish black. The beds are highly fissile and the leaves or laminae are very thin in all natural exposures, but in fresh sections the beds appear to be thick bedded and solid or massive. They are not weather resistant, for the most solid portions need only a season of freezing and thawing to turn the outcrop into a crumbling mass of disintegrated material. In some localities further decomposition of such material produces a whitish to yellow and blue tenacious clay.

It would appear that at least locally the Huron shale possesses more clay minerals and (or) clay-sized particles than the Cleveland shale, which gives the Huron plastic qualities not possessed by the Cleveland. However, mineralogical data to substantiate this assumption are lacking. Locally there are highly bituminous black shale beds having somewhat the appearance of impure cannel coal, containing in places the remains of plants accompanied by thin films of true coal.

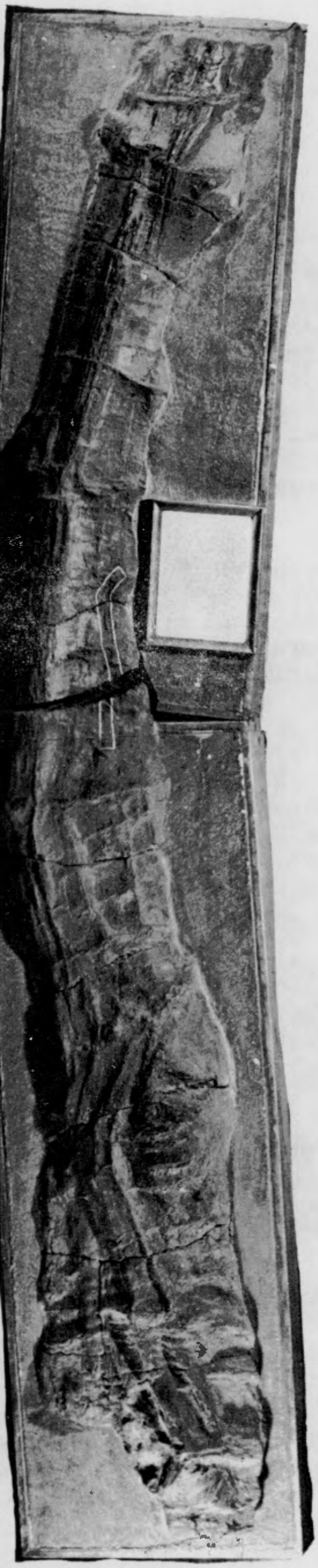
Spheroid and, in the lower part of the shale, elongate concretions are abundant, varying from half a foot to 15 feet in diameter. The smaller ones are composed almost entirely of iron-sulfide minerals; the larger ones of impure carbonate. The latter ordinarily show vertical lines of fracture and some have well-marked horizontal lines of stratification (figs. 10-D and 10-E). Many of these fissures are filled with crystals of celestite, barite, pyrite, marcasite and calcite. A nucleus made of organic or, as is more common, mineral matter is ordinarily found at the center.

The shales are so highly charged with iron sulfides and potash feldspars that their weathering produces sulfur and potash. Many exposures protected from the rain have a coating of efflorescence of alum and melanterite which may attain a thickness of three-fourths of an inch. Some nearly pure sulfur deposits of equal thickness may be observed. Mineralogically, Nelson (1955, p. 31) has found the Huron shale to be a quartz-illite-chlorite rock, even in the clay fraction. Kaolinite is normally absent, and the carbonate is commonly calcite.

Land plant fragments are abundant in the Huron shale (fig. 6). They are represented as plant impressions, "spores," and isolated thin films of coal which may be found at almost any horizon of these rocks. In addition to this flora assemblage a fair number of fauna phyla are represented. The most abundant fauna consists of conodonts, lingulids, orbiculoids, pelecypods, gastropods, and fishes.

Thickness

Because of difficulty in recognition of boundaries of the Ohio shale members, very little accurate information has been compiled on the thickness of the Huron shale. Nowhere is the total thickness seen in outcrop. Stout and others (1943, opposite p. 108) have reported an average thickness of 410 feet for the Huron shale.



Distribution

The Huron is recognized by subsurface means in northeastern Ohio as far east as the Ohio-Pennsylvania line. It is traced westward by well records and outcrops beyond its type area along the Huron River to the limits of the "black shale" outcrops. Southward along the strike of the outcrop, various workers have used a very loose definition for the vertical limits of the Huron shale.

Some geologists have used the term "Huron shale" synonymously with the name "Ohio shale." Orton (1874, p. 616-618), in reporting on the black shale of Pike County, considered the entire shale sequence as Huron shale. In his discussion of the black shale, Orton (1874, p. 617) reported:

> Spheroidal concretions... abound in the middle portions of the series ... [Though remains of fossil fishes have been found in the centers of these concretions in northern Ohio, the] only fossils noticed in concretions here [Pike County] are of vegetable origin, and these are very rare.

The suggestion is that these are carbonate concretions, so we may presume that both the Cleveland shale and the Huron shale are present in Pike County.

Lamborn and others (1938, p. 30-31) have reported a 52-foot exposure of Ohio shale along Sulphur Creek, Green Township, Adams County, consisting of black carbonaceous shale with a few large spherical carbonate concretions. Since this exposure is within sight of the Ohio River, it is safe to assume that rocks of the Huron shale lithologic type carry across the length of Ohio. Kindle (1912, p. 199) said, "The spherical concretions are a persistent feature of the lower or Huron shale as far south as the first tier of counties in Kentucky."

Figure 6. - Callixylon newberryi (Dawson) collected from the basal Ohio shale, Lewis Center Run, Delaware County, Ohio.

CHAGRIN SHALE

Definition

The name "Chagrin shale" was first used by Prosser (1903a, p. 521, 533-534) as a substitution for Newberry's preoccupied term "Erie shale." The name was derived from the Chagrin River along which the type section is located. The type section is thus described by Prosser:

> The name Chagrin formation is, therefore, proposed for this mass of argillaceous and arenaceous shales and calcareous layers on account of the excellent exposures on the banks of this river extending from Willoughby to the south of Pleasant Valley. With perhaps the exception of the cliffs on the shore of Lake Erie, there are probably no finer outcrops of the formation to be found than those forming the steep banks of the Chagrin River.

Cushing and others (1931, p. 32) did not recognize the presence of Huron shale underlying the Chagrin shale in the Cleveland area. Cushing wrote :

> ... These alternating black and gray shales with a thickness of more than 600 feet, were called Huron shale by Newberry, who correlated them with the shales along the Huron River, the type locality. Newberry's view is still held by many geologists. Others, of whom the writer is one, believe that the two shales have nothing to do with each other, that these underground shales of the Cleveland section pinch out before the Huron River is reached, and that the true Huron shale is a higher formation and is wholly unrepresented in the section at Cleveland. The lower part of the Chagrin shale is also not exposed in the Cleveland region.

The fieldwork for Cushing's report on the Cleveland district, Ohio, was virtually completed by 1912. The black shale equivalent of the Chagrin, according to Prosser (1912, p. 515), is the Huron shale. Prosser's studies of the Cleveland, Chagrin, and Huron shales from Cleveland westward to the Huron River have led him to the conclusion that the black shales gradually replaced a large portion of the bluish or gray shales and sandstones of the Chagrin member. More modern interpretations (Pepper and others, 1954, p. 14, fig. 6; Nelson, 1955, p. 30) place the Huron shale beneath the Chagrin shale and suggest that the Chagrin pinches out before reaching Norwalk, Ohio. In Cushing's 1931 report no further mention is made of the Huron shale as a higher formation. His columnar section (Cushing and others, 1931, fig. 3, p. 28) places an unconformity between the Chagrin and Cleveland shales. Cushing's (1912, p. 583) interpretation of an unconformity between the Chagrin and Cleveland shale is based on overlapping relationships of the shales, change of direction of source of sediment, and changes in direction of dip.

Eastward from Ashtabula County, Ohio, into western Pennsylvania, the upper beds of the Chagrin are massive fossiliferous siltstone, named by White (1881, p. 97-98) the Riceville shale. According to Cooper and others (1942, p. 1752), the Chagrin shale represents the western facies of the Conewango stage, including most of the Chadakoin beds of New York and Pennsylvania. Cooper believes the Chagrin is terminated by the Riceville-Oswayo shale.

Character

Only a few geologists have made more than a cursory investigation of the Chagrin shale. Most workers have accepted this unit as a noncarbonaceous clay shale occupying a position between two highly carbonaceous fissile blue-black shales. Our best description of the characteristics possessed by the Chagrin shale is furnished by Cushing, who wrote (1931, p. 33-34) as follows:

> The formation consists characteristically of blue-gray clay shale. In the unweathered material shaly cleavage is not prominent... Fragments of the rock are readily crushed to an impalpable powder beneath a hammer or pestle. On exposure it weathers very quickly to a soft sticky clay instead of crumbling to platy fragments. As exposed in steep cliffs along the streams it is so soft yet so tenacious that it becomes gullied by the rains from top to bottom... Stones thrown against such a cliff when it is damp often adhere or even deeply embed themselves instead of rebounding and falling to the base.
>
> Thin layers of flattened concretions 1 inch or less in thickness and from 3 to 8 inches in diameter occur in the formation. The concretions are blue within and are exceedingly tough and hard, containing a considerable percentage of lime and iron carbonates, On exposure to the weather they stain reddish by the oxidation of the iron to limonite.
>
> Layers of shaly sandstone, generally thin but reaching in places a thickness of 6 inches, are of common occurrence in the formation but are very irregularly distributed. As a rule they contain many flakes of silvery mica, and in places they are finely laminated. They commonly contain marcasite, and marcasite concretions are scattered throughout the formation.
>
> South and east of Cleveland the extreme upper part of the formation is of somewhat different character. Sandy greenish-gray shale of slightly calcareous nature is interbedded with the soft blue shale, and locally thin bands of gray impure limestone are also found. Calcareous concretions appear in the soft shales in spotty fashion instead of being in continuous bands, and they are much less flattened than the concretions in the bands. These upper beds contain fossils more or less abundantly and in that respect also differ from the main mass of the formation.
>
> West of Cleveland the upper part of the formation becomes much more sandy. The sections along Big Creek and the Rocky River show a much greater proportion of sandy beds in the upper-most 50 feet of the formation than is found at or east of Cleveland. These beds are thinly laminated fine-grained gray micaceous sandstones, many of them containing marcasite, which are quite like the less common beds elsewhere. Here they are more numerous and thicker, a few beds reaching a thickness of 6 inches. In the most western localities, west of the Rocky River along the lake shore, thin beds of black shale are interbedded with the blue shale and sandstone in the upper part of the formation. These beds are softer and less black than the typical black shale of the district but are quite distinct from the blue-gray shale.

The Chagrin formation increases in silt and sand content eastward toward the Pennsylvania border, and similarly, crossbedding and ripple marks become more common. In eastern Ashtabula County, Ohio, and western Pennsylvania the upper beds of the Chagrin shale are massive fossiliferous siltstones. Nelson (1955, p. 27) reports that the zone of fossiliferous strata in eastern Ohio extends for several hundred feet down into the formation below the Cleveland shale. Many zones have been recognized (Chadwick, 1925; Caster, 1934) which tie these rocks in with stratigraphic horizons of the Devonian rocks of northwestern Pennsylvania and western New York, but no detailed analysis of the faunas and their stratigraphic relationships has yet been attempted. These beds or their equivalents, which in Pennsylvania were called the Riceville shale by White (1881, p. 97-98), are overlain by the Cussewago sandstone or stratigraphically higher beds.

Mineralogically the Chagrin shales and siltstones are characterized by their quartz-illite-chlorite-kaolinite content. In the clay fraction kaolinite is an important, but not dominant, constituent. Nelson (1955, p. 57) found that the clay-ironstone concretions of the Chagrin are composed of siderite (brown spar, $FeCO_3$), quartz, and illite-chlorite-kaolinite clay mineral material, the last in the proportion characteristic of the surrounding Chagrin shale. Nelson (1955, p. 29) also reports cone-in-cone structures present in the top of the Chagrin. From his lithologic description of the associated shale beds, most geologists would probably regard the shale beds containing the cone-in-cone structure as the lowermost beds of the Cleveland shale.

Thickness

The Chagrin shale has all the appearances of a wedge-shaped body deposited in a linear basin whose assumed long axis parallels the Appalachian geosyncline. The portion of this basin deposit represented in Ohio is thickest in the east and presumably pinches out to the west, in Erie and Huron counties. Southward from the Lake Erie counties, outcrop sections and well records show a maintenance of thickness of Chagrin-type rocks parallel to the purported axis of deposition. Northward the shale is beneath Lake Erie, and thickness records are not available. However, the total thickness of the black shale series in Ontario averages about 8 feet and is correlated with the lower part of the Ohio shale (Stumm and others, 1956, p. 11). Thus, it is probably safe to suggest that the Chagrin wedges out to the north.

In northeastern Ohio the Chagrin, according to subsurface records, reaches a maximum thickness of about 1200 feet. Westward it gradually thins to a few feet in Erie and Huron Counties, and one can assume that the strand line was only a few miles beyond the present limits of preservation. Some geologists believe that the Chagrin entirely pinches out before it reaches the Huron River; others adhere to the opinion that the Chagrin rock type changes laterally to the west into a black shale. Cushing (1931, p. 33) has mapped the Chagrin beyond the south limit of the Cleveland quadrangle. Stauffer (1944, p. 255) has reported 460 feet of Chagrin present in the core from the limestone mine located near Barberton, Ohio. There are no scientific records, from either the subsurface or the outcrop, concerning the presence of Chagrin shale to the south. Investigations of the outcrop sections throughout the counties southward from the lake counties have reported gradual thinning of the Chagrin, with the last vestige found in Crawford County.

The work of Cushing (1931, p. 27), Winslow and others (1953, p. 51), and others in the Lake Erie outcrop region has recorded an average thickness of 500 feet for the Cleveland region. South of and roughly parallel to the axis of Chagrin deposition Stauffer (1944) reports a thickness of 460 feet for the Akron area. Along the western edge of the north-south outcrop belt, which approximates the Chagrin shale depositional axis, the shale is not recognized. Cursory examination of well cuttings by the writer and examination of subsurface records of the Ohio Division of Geological Survey substantiate the assumption that the Chagrin shale is present in the subsurface the full north-south length of Ohio, and that it thickens to the east.

Distribution

The area of outcrop of "recognized" Chagrin shale is limited to the counties bordering Lake Erie. The areal geology map of the Berea quadrangle by Cushing (1931, p. 20) shows the Chagrin shale confined largely to the slopes bordering Lake Erie, and the general dip of the rocks to the west, according to Cushman, carries the Chagrin below lake level within a short distance.

East of Berea the Chagrin rises above the level of Lake Erie, and the outcrop widens to the east as the dip brings more of the shale above lake level. Westward the Chagrin shale diminishes in thickness. Kindle (1912, p. 201-202) wrote:

> ...In the Huron River section the moderately coarse sandstones of the Chagrin have disappeared altogether. While bands of blue argillaceous shales interbedded with black shale are conspicuous in the middle portion of the Huron River section, it appears impossible to distinguish the exact limits in this section of the portion equivalent to the Chagrin of the more easterly sections. Although the Chagrin epoch of sedimentation is believed to be as fully represented there as in the Cleveland section, it appears better from the taxonomic viewpoint not to attempt to apply the term Chagrin to any part of the Huron River section but to assign the whole of it to the two divisions which are preeminently black shales... The middle portion of the Ohio shale group as exposed along the Huron River is probably one-third or one-fourth blue shale... [It appears that] the Chagrin west of Cleveland grades into and becomes interbedded with the black Cleveland shale... [and] it seems to be impracticable to discriminate the precise limits of the Chagrin. The essential fact or feature involved in the preceding discussion of the sediments of the Ohio group is the marked lithologic differences between eastern and western sections and the decrease in coarseness of the Chagrin sediment from east to west or in a direction away from their source.

Winchell (1874, p. 264) observed the Chagrin shale in Polk Township, Crawford County, but believed that the existence of this shale south of Crawford County was purely hypothetical. The few arenaceous gray beds present in the middle portion of the Ohio shale throughout the more southern counties no doubt are the last vestiges of the Chagrin shale. These gray beds do not have lateral continuity and are not mappable; thus, it is best to regard the Chagrin as a northern member or facies of the shale sequence as observed on the outcrop. Determination of the subsurface limits of the Chagrin will have to await future detailed studies of the shale sequence.

CLEVELAND SHALE

Definition

The name "Cleveland shale" first was suggested by Newberry (1871), who applied this name to the black bituminous shale, 20 to 60 feet thick, underlying the Bedford shale in northern Ohio. The type section is along Doan Brook in the eastern part of Cleveland, Ohio.

Before Cushing (1912, p. 583) published his paper on the age of the Cleveland shale of Ohio, this shale was regarded as the grayish-black shale which lies above the Chagrin shale, and which upon weathering produces thin reddish-brown chips. However, Cushing divided it into two parts. The upper is the typical hard dull grayish-black shale which weathers to thin reddish-brown chips. The lower part contains, in addition to beds of bluish-gray and gray clay shale, some thin gray to brown siltstone, nodules of pyrite, and several siliceous limestone layers that are characterized by cone-in-cone structures. This lower part was named the Olmsted member by Cushing and is confined to the outcrop area west of Cleveland. Cushing was of the opinion that the upper part of the Cleveland shale is present to the east as well as to the west of Cleveland. Pepper and others (1954, p. 16) and other later investigators feel that Cushing's Olmsted member represents the interfingering of the black shales of the Ohio and the gray shales of the Chagrin prior to the main eastward transgression of the sea that deposited the main mass of Cleveland shale. Nelson (1955, p. 21-27) has observed that the Cleveland shale is not a homogeneous lithologic unit. He says that laterally three distinct changes occur in the character of the Cleveland and refers to these as the Trumbull (eastern) facies, Cleveland (central and typical Cleveland rock type) facies, and Vermilion (western) facies. This is the first time that facies concepts, as such have been applied to the Cleveland shale. In order to use the word "Cleveland" as a facies term, Nelson has referred to the Cleveland shale of other authors as the "Cleveland horizon."

It is impossible to pick an unequivocal base for the Cleveland shale with our present understanding of this unit. It is perhaps desirable to place the base of the Cleveland at the bottom of the lowest siliceous limestone possessing cone-in-cone structure. Such structures are frequently noted in close proximity to lighter colored shale beds that have a Chagrin shale affinity. The upper limit of the Cleveland shale is the topmost black shale bed. This interpretation of the Cleveland shale limit generally follows that proposed by Kindle (1912, p. 198, 199).

Karhi (1948, p. 12), who studied the cone-in-cone structures of the Ohio shale in the Columbus region, wrote: "The writer does not believe that the structure [cone-in-cone] is any better developed in the upper part than in the lower or middle parts of the Ohio shale." However, he did not present any evidence to substantiate this statement. A review of Karhi's paper failed to disclose a reported section in which he had observed cone-in-cone structures below the highest spherical calcareous concretionary bed in that section of the State. His best described section was measured in the Narrows, $1\frac{1}{2}$ miles north of Worthington, Ohio. In the description of this section Karhi (1948, p. 27) reported the following concerning the cone-in-cone structures: "Large spherical calcareous concretions of from 3 to 4 feet in diameter are found below the cone-in-cone layers..." Clifton (1957) has found cone-in-cone or similar structures typically appearing on the outer edges of the carbonate concretions in central Ohio.

Character

Lithologically the Cleveland member is persistent in its gross aspects throughout the area of outcrop. There are local variations, and we find an arrangement of unlike and intergrading strata not easily described accurately and consistently in any scheme of taxonomic nomenclature. Nelson (1955) has applied to the Cleveland shale the facies concept, which might be accepted by future researchers in their studies of this shale. However, Nelson admits that boundaries between his facies are completely gradational and difficult to define.

The fresh shale, which is bluish black to brownish black, turns to coffee brown upon weathering. In fresh exposures the shale is very compact and massive to platy, but after slight weathering it becomes thinly laminated, fissile and brittle. Upon extreme weathering it turns dark gray and breaks down into flaky pieces, but does not acquire the real plasticity of a clay shale. Primary and secondary deposits of pyrite are present in considerable quantities along the laminae as concretionary masses and (or) as finely disseminated pyrite. When the shale is chipped it gives off a gaseous or petroliferous odor which is indicative of its high carbonaceous (kerogen) content.

Irregular concretionary masses occur in places, but they are not of the spherical form that characterizes the concretions in the Huron, and they are less calcareous. Where the Cleveland shale is typically developed, thin siliceous limestone beds with cone-in-cone structure are present. The cone-in-cone structures reported by Nelson (1955, p. 29) to be present in the Chagrin shale would be regarded by most investigators as belonging to the basal Cleveland member. Nelson mentions these structures as follows:

> In the vicinity of Berea the dark shale at the top of the Chagrin has practically eliminated the normal gray shales of that formation. Here there occur calcareous layers, cone-in-cone concretions, and thin layers of harder, blacker shale more like the Cleveland shale.

In the Lake Erie region where Cushing's Olmsted member is recognized, the Olmsted consists of many beds of bluish-gray clay shale and black shale ranging from 0.1 foot to several feet in thickness. In addition there are some thin gray-to-brown siltstones, many small nodules of pyrite, and several thin siliceous limestones that are characterized by cone-in-cone structure.

Most features common to the Huron shale are likewise found in the Cleveland shale. Plant material has benefited the shale with its bituminous content to produce cannel coal as well as fragments of true coal. By chemical weathering, minerals containing iron, sulfur, and potassium in the shales have been altered to form deposits of alum, melanterite, and sulfur so commonly associated with weathered outcrops of the Cleveland shale. Part of the Huron shale flora and fauna is also common to the Cleveland shale. This similarity of paleontological material, which for the most part has a long stratigraphic range, is a deterrent to assigning age relationships to the Ohio shale members.

The latest stratigraphic concept of the Cleveland shale is that proposed by Nelson (1955), who concluded from his studies in northern Ohio that the "Cleveland horizon" is represented by three facies. He calls these, from east to west, the Trumbull, the Cleveland, and the Vermilion--each facies being named for the city that lies about midway through the width of its belt. The middle, or Cleveland, facies is the typical black carbonaceous pyritic Cleveland shale which is massive where fresh and fissile where weathered. A few pyrite nodules occur, but the cone-in-cone concretions, which occur at the "Cleveland horizon" in the Vermilion facies, are not found in the typical Cleveland shale. The contact with the underlying Chagrin shale is at many places very sharp, but not disconformable or diastemic. D. H. Dunkle, according th Nelson, reports that no remains of fish typical of the black shales of northern Ohio have been taken from the Cleveland facies.

The eastern, or Trumbull, facies is characterized by less stratigraphic thickness and by greater sand content in the black shale than is typical of the Cleveland shale. In some localities of the Trumbull facies, sandy beds occur at the base of the interval, whereas beds like the typical Cleveland shale occur in the upper part. The sandy beds are blackish carbonaceous massive siltstone containing abundant specular mica. The associated black shales also contain abundant specular mica and may contain more and coarser grained quartz than does the typical Cleveland shale. Some of the sandy beds occur as flagstones distributed throughout the interval. It is possible that both the upper and lower contacts of the Trumbull facies are slightly disconformable, but in the areas of exposure of the Cleveland and Vermilion facies there is no disconformity at the upper or lower contact of the "Cleveland horizon." Nelson says that east of Trumbull and southeast of Peninsula the Trumbull facies passes into the upper beds of the Chagrin shale and loses its identity.

The most westerly, or Vermilion, facies is less massive and probably less carbonaceous and pyritic than the typical Cleveland shale. It breaks with a flaky fracture, is slightly softer then typical Cleveland shale, and tends to show a lamination which Nelson suggests is due to a decrease in carbon and pyrite content. Bands of gray shale alternate with the black shale. Polished rock sections of these alternating shale bands studied by Nelson show that there is a distinct break between the black shale bands and the gray shale bands, caused by the occurrence of carbonaceous material in the black but not in the gray bands. Pyritic nodules are common in both black and gray bands. Tiny flecks of carbonate are present in fresh hand specimens of the Vermilion facies, and discoidal carbonate concretions are found near the top of the facies. Nelson reports that D. H. Dunkle has collected the arthrodire *Dinichthys herzeri* and fragments of teeth, spines, and plates of sharks and arthrodires from the Vermilion facies. The upper limit of this facies may be either slightly diastemic or completely gradational with the overlying Bedford shale.

Mineralogically the rocks of the Cleveland interval are reported by Nelson (1955) to be a quartz-pyrite-illite-chlorite type. Kaolinite is either absent or present in very small amounts; chlorite is normally present. Strata of the "Cleveland horizon" are composed predominantly of quartz-illite rocks. Nelson found that quartz occurs even in the clay fraction. Rocks of the Trumbull facies contain very little clay-sized material. A little kaolinite is present in some samples of the Vermilion facies. Small quantities of carbonate minerals are present in the black shales of the Vermilion facies, but there are none in the Cleveland and Trumbull facies. Carbonaceous material and pyrite seem to be most abundant in the black shales of the Cleveland facies, somewhat less abundant in those of the Vermilion, and least abundant in those of the Trumbull.

Thickness

At Cleveland, Ohio, the Cleveland shale is 20 to 50 feet thick. Eastward from Cleveland this shale gradually thins and seems to pinch out near the Pennsylvania-Ohio boundary. Cushing (1912, p. 583-584) states that the Cleveland shale is absent on the east bank of the Grand River in Ashtabula County, but is present on the west bank. Pepper and others (1954, p. 16) are of the opinion that eastward the Cleveland shale grades laterally into the upper beds of the Chagrin shale. Nelson (1955, p. 20) says that westward from Cleveland, Ohio, the Cleveland shale increases in thickness at the expense of the gray shales and siltstones of the Chagrin shale. The Cleveland shale southward from Cleveland thins to 6 feet near Peninsula, on Slipper Run, (Prosser, 1912, p. 149), and westward it thickens to more than 60 feet in Erie County.

South of Erie County not enough detailed stratigraphic sections have been measured to delimit the Cleveland shale; consequently the thickness is not known.

Distribution

The Cleveland shale has its best development around the mouth of the Cuyahoga River in Cuyahoga County, where it attains a thickness of 54 feet. The Cleveland shale has been considered a mappable unit by some geologists; it is present from the eastern State line in Ashtabula County westward to the limit of outcrop in Erie County; southward from Erie County it can be traced into Morrow County, where, according to Winchell (1874, p. 263-264), the last vestige of the Chagrin shale is to be found near South Woodbury (Peru Township). Inability to recognize the Cleveland shale southward along the outcrop results from parallelism of the bedding with shale units above and below, paucity of outcrops, lack of fossils identifiable with the Cleveland shale, and frequent absence of gray shale beds in the position normally occupied by the Chagrin shale.

Orton (1893, p. 23) who believed that the Cleveland shale extends on southward into Kentucky, reported:

> ...It is this element [Cleveland shale] that proves most persistent in the southern extension of the black shale. The shale that covers the Lower Silurian limestone in central Kentucky is the upper or Cleveland division, as its most characteristic fossils ...prove.

The Cleveland shale can be assumed to extend south of Morrow County by virtue of the presence of cone-in-cone structures in the black shales. Many outcrops of the Ohio shale in Logan County have been noted by the present writer to possess cone-in-cone structure. Such structures have been observed also by Kindle (1912, p. 199) in the outcrop as far south as Irwine, Kentucky. Due to the paucity of complete sections of shale studied in southern Ohio, there may be failure in noting the presence of these structures rather than their absence. It is reasonably safe to assume, then, that the Cleveland shale is present beyond the southern limits of Ohio.

In the light of present knowledge it is impossible to say whether or not the Cleveland shale is present west of the Cincinnati arch in northwestern Ohio.

BEDFORD SHALE

Definition

Newberry, (1871, p. 21) assigned the name "Bedford shale" to the red and blue clay shale, 60 feet thick, overlying the Cleveland shale and underlying the Berea grit (sandstone) in northern Ohio. The Bedford is the lowest member of the Waverly group. The term "Bedford" has been variously used to describe several different rocks. A historical résumé of its use is furnished by Prosser (1905, p. 20-21), as follows:

> Bedford shale was named by Newberry in 1870... and fully described by him in 1873. The term "Bedford rock" appears in Richard Owen's description of the geology of Lawrence County, Indiana, published in 1862, but it was not used as the name of a geological division and was not described. The next occurrence of Bedford stone is in the Indiana report published in 1874, which it will be noted is one year later than Dr. Newberry's full description of the Bedford shale of Ohio, in which Professor John Collett described the "Geology of Lawrence County" and under the geological division of the St. Louis limestone... the famous "Bedford stone"...
>
> It is evident, however, on reading the report, that Professor Collett did not use the term "Bedford stone" as the name of a geologic unit. It was, however, excellently described in 1896 by Hopkins and Siebenthal under the formation name of the "Bedford oolitic limestone." Finally in 1901 Professor Edgar R. Cumings,... wrote as follows: "Since the term Bedford as the name of a formation is preoccupied, having been applied to the 'Bedford shale' of northeastern Ohio in 1870, the writer proposes the name 'Salem limestone' for the rocks called Bedford limestone by Hopkins and Siebenthal." It is the writer's opinion concerning the formational names of "Bedford shale" and "Bedford oolitic limestone" that the former is the one entitled to stand and this opinion is sustained by the Committee on Geologic Names of the United States Geological Survey. The writer submitted the question to this committee and the following decision was communicated by the Director, Hon. Charles D. Walcott: "(1) That Bedford rock was used by Owen in 1862 in a 'Report of geological reconnaissance of Indiana, 1859-60,' p. 137, but the usage is so indefinite as not to constitute a pre-emption of the term for stratigraphic purposes. (2) Bedford shale is a term first employed by Newberry in 'Ohio Geological Survey report of progress, 1869,' p. 21, and this usage should stand. Furthermore, it is understood here that Mr. Cumings has recently proposed to drop the name of Bedford limestone of Indiana, and substitute for it 'Salem limestone.' Both sides of this question were fully presented in the Journal of Geology, in 1901, by Siebenthal, Cumings, Prosser, and Chamberlin."

In northern Ohio the Bedford shale contains two named massive siltstones, both of which are very local in extent. The lower one was named Euclid sandstone lentil (Morse and Foerste, 1909, p. 136) and the upper one, Sagamore sandstone lentil (Prosser, 1912, p. 87-88). Pepper and others (1954, p. 12) have renamed these the Euclid siltstone member and the Sagamore siltstone member. The Euclid siltstone member reoccurs in the subsurface some 80 miles south of the Lake Erie shore, where, on the basis of lithologic and mineralogical evidence, it is generally referred to as the Second Berea sand. Nelson (1955, p. 12-20) divides the Bedford shale in northern Ohio into three parts, which are named, perpendicular to the original strike, from east to west: eastern, central, and western divisions. The western boundaries of his eastern and central divisions are just west of the cities of Bedford and Berea, respectively.

The Cussewago sandstone, as redefined by DeWitt (1946), is present in Trumbull County, presumably was deposited from a southeastern source (DeWitt, 1951, p. 1354), and is, for the sake of simplicity, here included with the Bedford shale. The Cussewago sandstone rests upon the Chagrin shale in eastern Trumbull County and upon the Cleveland shale in western Trumbull County (DeWitt, 1951, fig. 3, p. 1351). Recent investigations by Pepper and others (1954, p. 19-20) have shown that the shale named Cussewago by White (1881, p. 94-96) is the eastern part of the Bedford shale of northern Ohio. Nelson (1955, p. 65-66) is of the opinion that the Cussewago is intimately related to Bedford sedimentation. He regards the Cussewago as a western and finer grained equivalent of the Knapp and Pocono sandstones and conglomerates of western Pennsylvania. Westward in Ohio the Cussewago passes into the flagstones of Nelson's eastern division of the Bedford shale.

The environmental conditions of deposition had changed drastically before the basal beds of the Bedford were deposited. This is emphasized by a faunal change and by a vast percentage increase of silty material. This environmental change has led to two schools of thought--one championed by Caster (1934) and Pepper and others (1954), and the other by Nelson (1955)--concerning the depositional relationship of the Ohio and Bedford shales in Ohio.

Regionally the Bedford shale appears to have been deposited on top of the Cleveland member with a very short cessation or no cessation of sedimentation. Because the rocks lie practically horizontal, many sections display a transitional zone of mixed rock types between these two shales. Hyde (1953, p. 29-34) was of the opinion that a period of erosion and slight tectonic activity preceded the deposition of the Bedford shale in central and southern Ohio. Consequently, he did not adhere to the opinion held by some that a transitional zone existed between the Bedford and underlying shales. Hyde (1953, p. 30) states:

> The contact at all points has every appearance of having been affected by a mechanical movement within the shales above and below it subsequent to deposition, as a result of which tongues of the Ohio and Bedford are respectively thrust each into the other.

Though local diastems can be expected in any sedimentary sequence, it may well be that the mechanical disturbances described by Hyde represent mud slides and are the same structures described and called "flow rolls" by Pepper and others (1954, p. 22) (see fig. 7). It is almost essential that the sediments possess ample water and be plastic enough to slip or glide when loaded. Thus, it is doubtful whether any criteria of a diastem could be recognized regionally which would be indicative of erosion or cessation of sedimentation between the two sedimentary units.

The base of the Bedford shale is comparatively distinct, though in many places transitional, in both the outcrop and the subsurface. The base is always taken as the top of the uppermost black shale bed. Any extremely thin black shale stringers of the transitional zone are considered Bedford. The contact between the Bedford shale and overlying Berea sandstone is marked by a disconformity in northern and central Ohio. South of Lithopolis the Bedford shale and Berea are virtually conformable. In southern Ohio it becomes impossible to distinguish between the Bedford shale and Berea sandstone. Hyde (1911, p. 257) has suggested that in southern Ohio the Berea is a phase of the Bedford. South of Chillicothe the ratio of shale to siltstone decreases until finally in the vicinity of Buena Vista the Bedford is composed largely of siltstone. The siltstones of the Bedford cannot be separated from those of the Berea in this region; therefore the two are discussed here as a single unit.

Two relatively recent geological papers have been published which comprehensively discuss the Bedford shale. These are "Mississippian formations of central and southern Ohio" by J. E. Hyde (1953) and "Geology of the Bedford shale and Berea sandstone in the Appalachian basin" by J. F. Pepper and others (1954). Hyde's publication is the summary of a lifelong study of the Mississippian formations, a study he began as a boy of nine and actively pursued until his death 43 years later, in 1936. Pepper's treatment is a U. S. Geo-

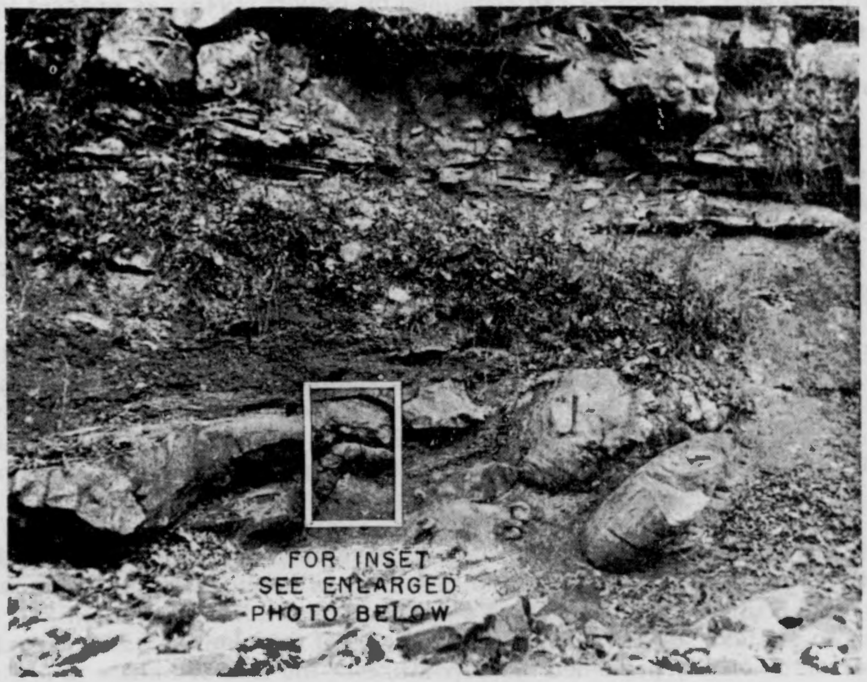


Figure 7. - Flow rolls in the Bedford shale.

logical Survey Professional Paper which includes field observations, laboratory studies, and evaluation of existing data. The reader may rely upon these two publications for any exhaustive study of the Bedford formation.

Character

The Bedford depositional period ended the long reign of conditions of marine shale formation ushered in by the Olentangy shale. The Bedford shale environment was much different from that of its black shale predecessor. However, this change was perhaps no more drastic than that from Olentangy to Ohio shale deposition, save in its comparative abruptness. This new cycle of sedimentation began with faunal changes, reworking of the black mud, introduction of the gray mud and silt, and dilution of the salt water with a large volume of fresh water. Though the invertebrate fauna occurring in the lower beds of the Bedford shale has not been fully described, it is very useful for interpretative purposes.

The Olentangy and Ohio shale sediments seem to have been derived from land near sea level and (or) far removed from the depositional area. According to Caster (1934) the Bedford shale begins a new facies province in Ohio. He has proposed two sources for the clastic material of the Bedford, a concept that arose because of the variable character of the shale. The Bedford shale of eastern Ohio seems to be related to an Appalachian or eastern source. The very different beds that characterize this shale farther west might have been derived, according to Caster (1934, p. 156), from a western source, perhaps Cincinnatian. DeWitt (1951, p. 1367) and Pepper and others (1944, 1954) say the Bedford sediments were derived from a fresh-water river system formed in the newly uplifted northern drainage basin (southern Ontario), and were deposited southward as an ever lengthening and widening deltaic mass in the shallow remnant of the Devonian sea, whose northern shoreline roughly paralleled the present south shore of Lake Erie. Nelson (1955, p. 62-65, pl. 1, fig. 9) disagrees with a western or northwestern source of the Bedford sediments and is of the opinion that the various lithologic expressions of the Bedford formation are best explained by facies differentiation, with the sediments coming from an eastern source. Nelson offers structural, lithologic, stratigraphic, and mineralogical evidence to support his interpretation.

Since a marine delta environment is characterized by the interplay of marine and terrestrial influences, its deposits are much more dynamic than those characterized by shale deposits resulting from a black mud environment. Deposits of a delta are the most variable type known to geologists -- they frequently represent an intimate intermingling of marine, fluviatile, lagunal, terrestrial, and limnic environments. Since it is beyond the scope of this paper to provide a detailed discussion, the characteristics of the Bedford will be reviewed only in their broader aspects.

At its type section along Tinkers Creek, the Bedford is composed of gray and bluish-gray shale, nodular light-gray mudstones, and brownish-gray to gray irregularly bedded (flagstone) siltstone. There is a tendency for this flagstone to cluster in zones, which in the literature, have been called the Sagamore lentil (Prosser, 1912, p. 410).

Eastward from the type section of the Bedford, the silt and flagstone content increases, many invertebrate fossils are observable, and due to channels developed in the Bedford before Berea deposition the Bedford-Berea contact is very irregular. In the counties bordering Pennsylvania, the Bedford is composed largely of silty gray shale, hard silty gray mudstone, and thin platy gray siltstone. The Sagamore siltstone and Euclid siltstone members are both recognized in the outcrop eastward from the type section. Nelson (1955, p. 14) has reported as follows concerning the mineralogical constituents of his eastern division:

> Mineralogically the shales, siltstones... are quartz-illite-chlorite-kaolinite rocks, in which kaolinite is an important constituent of the clay fraction. Some of the sandstones and siltstones contain little argillaceous material.

Westward and southward from Tinkers Creek, deltaic characteristics of the Red Bedford delta are apparent. These rocks are composed predominantly of grayish- to dusky-red shale, but other types of rock, such as gray shale or sandstone and siltstone lenses, are abundant in many parts of the deposit. The central division of the Bedford according to Nelson (1955) shows two characteristic lithologic changes. A massive siltstone and a very fine grained sandstone body (Euclid and Sagamore siltstone members) are characteristic of the lower and middle portions, but reddish shales predominate in the upper part of the Bedford. Westward the siltstone and sandstones become thin, but the reddish shales increase in thickness to become the dominant rock type of the western division. Mineralogically the gray shales above and below the siltstone members are similar, containing quartz, illite, chlorite, and kaolinite. The reddish shales, which owe their color to hematite, mineralogically are a quartz-illite-chlorite-kaolinite rock. Illite is the dominant clay mineral of the gray and reddish shales in both the central and western divisions but kaolinite is also an important constituent in each.

In northern Ohio, the Bedford is predominantly a soft red clay shale, which weathers rapidly to a sticky red mud and forms outcrops that soon are obscured by slumping and soil creep. The basal beds of the Bedford consist of gray-black shale, a few intercalated ripple-marked siltstones, and local zones of distorted siltstones (flow rolls). The Bedford is in an unconformable relation with the Berea. In many places the erosional channels have cut entirely through the Bedford shale into the underlying Ohio shale, leaving the Berea sandstone in contact with the Ohio shale. The amount of red shale and the intensity of its color decreases southward from northern Ohio. The Bedford shale of central Ohio is predominantly a gray and gray-blue soft clay shale. In this area calcareous siltstones, ranging from 2 to 4 inches in thickness, are present in the upper 8 feet. Some thin gray silty mudstones are present in the base. Siltstones increase in number and thickness in the upper part of the Bedford south of Columbus. South of Chillicothe the upper third of the Bedford contains innumerable platy siltstones and layers of silty silicified shales; the Bedford as a whole grades from a soft clay shale in the lower part to thin siltstones and gray silty shales in the uppermost part of the formation. In the vicinity of Buena Vista the Bedford and the Berea are composed largely of siltstone and sandstone beds. Here no line of demarcation between the two formations can be drawn, and the two are considered as one unit. According to Hyde (1953, p. 36) the Berea and Bedford sandstone beds are identical except that the Bedford beds have a lime content while the Berea beds do not. The southern phase of the Bedford is characterized by the occurrence of some small nodules of pyrite, marcasite, and calcium carbonate in the upper part. The basal part contains a small fauna of invertebrate fossils.

Oscillation ripple marks are a prominent feature of the Bedford sandstones. The ripple crests are generally from 3 to 5 inches apart. This periodicity varies within a few feet on each surface. Hyde (1911, p. 257-269) published a report of a study of these features covering an area 20 miles wide and 115 miles long, starting in Delaware County and going to the Ohio River. He found that ripple marks are seldom noted in the lower part of the Bedford but appear rather gradually near the middle and increase toward the top. He found these ripple marks to be remarkably persistent in direction, trending northwest-southeast. In central Ohio they range between N. 40°W. and N. 55°W. Farther south the direction is alined more nearly east and west; on the Ohio River they range from N. 60°W. to N. 70°W. The cause of the progressive variation in direction is not apparent, but Hyde believed that the general persistence of direction indicated the approximate trend of the shoreline and that the ripple marks were formed parallel to this shoreline.

The thin stringers of black shale so noticeable in the basal part of the Bedford in northern Ohio, characterizing the transitional contact between the Ohio and Bedford shale, are missing along most of the western outcrop. In its area of outcrop, the contacts between the Bedford and its associated formations are generally not sharp breaks. These contacts are even more indiscernible in the subsurface.

Structural features characterizing the Bedford shale are mud cracks, "fucoidal" markings, ripple marks, and flow rolls. Flow rolls observed by Nelson (1955, p. 25-27) along the Rocky River and Skinner's Run sections have been described by him as being a few feet below the Bedford contact, well within the Ohio shale, although the Bedford-Ohio shale contact selected by other investigators places these at the base of the Bedford shale.

Thickness

Isopachous studies reveal extreme thickness variations for the Bedford shale (Pepper and others, 1954, pl. 7). It is not uncommon for the thickness to range from less than 50 feet to as much as 150 feet within the boundaries of an individual county. Thickness investigations of the Bedford have been inconclusive because the bottom in many places is not sharply defined and there has been postdepositional scouring of the top. The contact with the underlying Ohio shale is frequently transitional, and individual investigators are not always consistent in locating the boundary. Because of erosion of the top, a true thickness cannot be determined from individual sections or wells; even closely spaced sections or wells show great variations. Regionally, however, established thickness figures are believed to be reasonably accurate.

At its type locality along Tinkers Creek, the Bedford is about 85 feet thick. It thins eastward from the type section but thickens westward. If the strike of the Red Bedford delta of Pepper and others (1954, p. 45, pl. 7) is traced southward, it is noted that the Bedford thins away from the headwaters of the Ontario River, which transported the sediments. As the Bedford shale is traced eastward from the type area it thins from 85 feet to 44 feet near Wick, in southeastern Ashtabula County (DeWitt, 1951, p. 1357). Westward it attains a thickness greater than 150 feet in Erie and Huron Counties; and in some sections channelling has completely cut through the Bedford, leaving the Berea resting on the Ohio shale. Southward, parallel to the strike of the formation, the Bedford thins to 95 feet in Franklin County and to 85 feet at the Ohio River. The thinning in Kentucky is much more rapid than in Ohio. Hyde (1911, p. 267) reports the combined thickness of the Bedford and Berea as 46 feet only 18 miles south of the Ohio River and as only a few inches some 60 miles farther south in Kentucky.

Distribution

The Bedford shale crops out along the Lake Erie counties from the Pennsylvania border westward into Erie County. Here the outcrop belt turns southwestward, and the Bedford can be traced along the strike of the formation southward across the Ohio River into Kentucky. The Bedford is recognized by subsurface means in all the counties south and east of the area of outcrop.

BLACK SHALE PROBLEM

The "black shale problem" deals with the meaning of the shale sequence, first, in terms of its depositional environment and, second, in terms of its time-stratigraphic correlation with adjacent rock series. This problem has been the subject of vigorous controversy in the literature of stratigraphy itself and in the more general field of sedimentation for nearly all the years that American geology spans. The "age" problem is whether the "black shales" of the east-central interior are Devonian or Mississippian in age. These black thinly laminated carbonaceous shales have been assigned various names by different workers, according to the location at which they have been studied. Some of the names assigned are: Ohio shale, Chattanooga shale, New Albany shale, Exshaw shale, Mountain Glen shale, Grassy Creek shale, Antrim shale, Woodford shale, and Portage shale. These carbonaceous shales were deposited in an interior sea that extended from New York west to Oklahoma and south to Alabama. The boundaries of the interior sea may be taken roughly as the old land Appalachia (island arc megog belt of Kay, 1951) in the east, and Ozarkia in the west.

Origin of Black Shale

The prevailing interpretations by the various workers who have studied black shale deposition can be divided into those which advocate "deep-water" origin and those which advocate "shallow-water" origin.

Clarke (1903, p. 199-201) suggested that the black shales were deposited in an enclosed marine body of great depth and imperfect circulation which was being encroached upon by sandy sediments from the east. He believed that the fauna of the black shales indicates deep toxic (ferrous sulphide) water and that neither the type of plant remains nor the presence of such brachipods as Lingula, which could be attached to seaweed or floating logs and floated into any environment, proves near-shore conditions. Schuchert (1910, p. 446) stated that the black shale deposits denote closed or stagnant arms of the sea (like the present Black Sea) if the shales are widely distributed, and that they denote filling of holes in the sea bottom if they are of small areal extent.

Rich (1951, p. 2038-2039) has suggested that the Marcellus-to-Chattanooga bituminous shales represent poorly aerated water deposits in the deepest remaining unfilled part of the Devonian-Early Carboniferous Appalachian geosyncline. As the black shales were deposited, they were encroached upon by clino deposits along the southeastern and eastern sides of the water body. During the filling of the trough, the coarser clastic sediments built out a delta-like shelf (undaform) bordered by a foreset slope (clinoform) leading down to the deeper part of the basin (fondo). At intervals, perhaps because of more rapid sinking of the basin or less sediment supply, the black shale deposition extended farther landward over previously deposited sandy strata, resulting in the formation of at least four distinct units of bituminous shale during Middle Devonian and the early part of Late Devonian time. The fondo beds tended to merge toward the west into a single zone of bituminous shale (Ohio shale of south-central Ohio). Farther west the Ohio shale was joined by a bituminous shale of Early Mississippian age (Sunbury) to constitute the single unit called the New Albany shale.

According to Ulrich (1911, p. 356-361), the Paleozoic black shale deposits in America do not indicate either "stagnant" or more than usually "inclosed" bodies of water. The black-shale-depositing seas were no more enclosed than the limestone-depositing seas which occupied virtually the same areas in preceding and intermediate ages. Nor are the facts for the Ohio shale any different, except that the water during the time of Ohio shale deposition evidently invaded from the Gulf of Mexico. Ulrich states that deposition took place under varying conditions of depth and degree of enclosure - sometimes with perfect circulation (deep channels) and at other times with sluggish and imperfect circulation (broad shallow pans). At no time were marine animals abundant. He suggests that the black shales may have been deposited during a time of cool climate, but admits that climate is not a satisfactory explanation for the conditions of their deposition.

Grabau (1917a, p. 945-958) believes the black shales were formed in the shore zone of a transgressing sea and that they represent the reworking of a black carbon-rich residual soil formed on the underlying limestones during a preceding long period of peneplanation. He compares the richly organic muds now found in parts of the Vistula River estuary with the dwarf faunas of the Genesee shale to indicate that the Genesee shale was laid down in shallow estuaries under relatively fresh-water conditions. Grabau (1906, p. 593-613) says that the Ohio-New Albany-Chatanooga shale is an overlapping lithologic unit representing the shore facies of a transgressing sea moving southward over a very low land.

Klepser (1937, p. 166-172, 184-185) agrees with Grabau. He has found evidence that the Chattanooga is a basal shore deposit which thins out because of overlap of older layers by younger sediments as the Early Mississippian sea advanced southward. From this evidence he feels that the Early Mississippian seas were only a readvance of the latest Devonian sea invasion from the northwest.

Stockdale (1939, p. 38) has said:

> The Chattanooga "black shale" of Kentucky and Tennessee is another example of a time transgressing unit. Evidence strongly points to its being a shore or near-shore facies formed on the south shore of the Late Devonian-Early Mississippian sea which advanced southward upon a very low, nearly flat land surface. As thus conceived, it is a shore facies which accumulated while other marine deposition continued in the deeper water....

Nelson (1955, p. 69-79) regards the northern Ohio Devonian-Mississippian shale sequence as facies deposits representing part of the final phase of a geosynclinal cycle of sedimentation, and the rocks below the Bedford formation as clearly related to Appalachian geosynclinal sedimentation. Nelson believes that between the deposition of the Chagrin shale and the Berea disconformity the northern Ohio basin, with a maximum depth of 300 feet, gradually shallowed and filled as a consequence of the influx of sediments from the east. The deeper waters of the basin lay to the west. As the basin filled, the shoreline advanced westward from an original position in central Pennsylvania. He is of the opinion that the Berea sandstone represents the final stage of infilling of the northern Ohio basin before the beginning of another cycle of submergence and that with the Berea came the transition to fluviatile conditions.

Twenhofel (1939, p. 1196-1197) has suggested that the black muds which form black shales originate under conditions of poor water circulation. He believes that at best only limited quantities of oxygen can enter the sediments. Thus, toxic conditions develop, under which rapid accumulation of organic material takes place. Twenhofel states that, due to the wide range of physiographic aqueous conditions of deposition, there are no generalized conditions under which black shales are deposited; therefore, as Twenhofel concludes, "each black shale formation should receive interpretation on the basis of the characteristics of that black shale formation."

The black shales become progressively younger toward the west and south, and are correlated with the overlying beds to the north. This indicates that the black shales could be a time-transgressive unit. Hass (1947, p. 140-141) concludes:

> Campbell's Blackiston formation of Indiana is equivalent to the Huron shale and his upper New Albany is a correlate of the Sunbury shale. The Bedford shale, the Cleveland shale, and the Olmsted shale members are younger than Campbell's Blackiston formation but older than his Sanderson formation.

Hass (1947, p. 133) has found that faunally the conodont assemblage of the Huron (lower Ohio) shale has nothing in common with the Cleveland (upper Ohio) shale and that this difference indicates that the two units may be separated by a break in sedimentation. This recent investigation by Hass, therefore, suggests that the Ohio shale is not a time-transgressing unit.

Source of Carbonaceous Material

There has been much speculation concerning the bituminous content of the Devonian-Mississippian black shales, most of which contain from 10 to 20 percent of carbonaceous matter. Generally, such shales are not very fossiliferous, but the scales of small ganoid fishes and the singular denticles (conodonts) are almost always present, and frequently minute flattened (originally spheroidal bodies) spores of plants are found. Vast masses of the Ohio shale may be examined with the discovery of no other fossil evidence than seaweeds, which in some places cover the surfaces of the layers. The most common invertebrate fossils are species of Lingula and Orbiculoidea. A considerable number of placoderm fish remains have been found in the Ohio shale.

Orton (1882, p. 171-174) attributed the carbonaceous matter which the shale contains chiefly to the spores of seaweeds, or Lycopods. Newberry (1883, p. 357-369) objected to this postulate, saying that the carbonaceous matter is mainly derived from algae. He points out that samples of these shales examined chemically and microscopically by Dr. Julien failed to show any traces of the sporelike bodies; but that, on the contrary, the carbonaceous matter with which they were charged was in most cases plainly amorphous--irregular fragments resulting from the breaking down of vegetable matter.

Several recent researchers (Raymond, 1942; Winslow, 1954; Schopf, 1953; and Nelson, 1955) have interpreted the organic matter as being plant derived. Raymond (1942, p. 658-663) attributes the dark color of the shales to the large quantities of chitin (from chitinous skeletons) that drifted offshore with the finest grained particles of sediment and that on devolatization colored the muds of the pelitic zone. Likewise, organic matter, which through devolatization would produce a black pigment, is represented in the organic fraction of the shales by lignins, waxes, resins, and other vegetable products. Schopf (1953) has found that the organic matter of the Devonian-Mississippian shales include: Foerstia, Callixylon, and Protoaxites. Nelson (1955, p. 69) considers the carbonaceous matter of the black shales as being derived from humic colloids, as well as particulate plant debris, the ultimate source of which was land plants in the source area of the detrital sediments. He believes the source area for this carbonaceous matter in the Huron shale was in the west (from a low-lying cratonic land source), and that the source for the carbonaceous matter of stratigraphically higher black shales was in the east.

Some researchers hold that the carbonaceous matter was derived from pre-existing oil deposits. Gutschick (1947, p. 1185) believes that probably the large positive areas such as the Ozark dome, Nashville dome, and Cincinnati arch uplifted in late Ordovician time were regional oil structures. The local oil reservoirs were exposed by erosion from late Ordovician to late Devonian time and caused dissipation of the liquid bitumen. He says that the bituminous content of the black shales can be accounted for in part by the incorporation of the oil in the dark muds. Work performed by such researchers as Andrussow (1892), Brown (1904), Ellis (1907), Harder (1919), and Nadson (1904) has led them to suggest that the color of the black shales is due to a mixture of ferric hydroxide (or ferrous sulfide), manganese oxide, and organic matter. The organic matter is decomposed largely by the action of microorganisms, and during the decomposition hydrogen sulfide, ammonia, hydrogen, methane, and other gases are liberated. Iron salts were probably introduced from surrounding regions. Under strongly reducing conditions and in the presence of hydrogen sulfide these become converted to hydrous ferrous sulfide and are precipitated. The precipitated ferrous sulfide usually does not form pure deposits but becomes mixed with fine clastic material and organic matter to form black mud.

Correlation of Shale Strata

The paleontological (age) phase of the "black shale problem" is concerned with the correlation of Upper Devonian and Lower Mississippian strata of Ohio with those of Pennsylvania and New York and states to the south and west. From the time of the earliest investigators the age of these shales has been in dispute. The literature relating to the Devonian age of the Ohio shale appearing previous to 1898 has been summarized by Girty (1898, footnote p. 385-386) as follows:

> At first, as is well known, the black shale of the central States was correlated with the Marcellus shale of New York (Hall, 1842, this Journal, vol. XLII, pp. 57, 62; Hall, 1843, Trans. Assoc. Am. Geol. and Nat., vol. I, 1840-1842, pp. 272, 280, 289; Hall, 1843, Geology of New York, pt. 4, Survey of Fourth Geol. District, p. 519; Rogers, 1843, this Journal, vol.

XLV, pp. 161, 162; Hall, 1845, Boston Jour. Nat. Hist., vol. V, No. 1, p. 10; Hall (somewhat doubtfully), 1862, Fifteenth Ann. Rep. New York State Cab. Nat. Hist., p. 81); but in 1847 de Verneuil published his paper on the parallelism of the Paleozoic deposits of North America with those of Europe (Bull. Geol. Soc. France (2), vol. IV, pt. 1, pp. 646-710) in which he showed that the formation in question was the equivalent of the Genesee, (Even before this Owen thought that the balance of probabilities was in favor of correlating the black shale with the Genesee (this Journal, vol III, 1847, p. 72) while toward the same conclusion tend Yandall and Shumard (contributions to the Geology of Kentucky, Louisville, 1847, p. 16), who identify some Lingulas and Orbiculoidea from the Black Slate of Indiana and Kentucky as Schizobolus concentricus, Lingula spatula and Orbiculoidea lodensis, all three described from the Genesee shale) and since that time geologists have, for the most part, sanctioned this correlation. Hall published a condensed and annotated translation of this work (this Journal, vol, V, 1848, pp. 176-183, 359-370, and vol VII, 1849, pp. 218-231) in which as coming from de Verneuil are found on p. 182 (footnote, vol. 5) an intimation and on p. 370 (vol. VII) a distinct statement of the correlation of the Black Slate with the Genesee, a conclusion of which in a footnote on p. 182 (vol. V) the translation appears to concede the correctness. Later, however, he recedes from this position, for the black shale at Rockford, Indiana, he again refers to the age of the Marcellus shale (Thirteenth Ann. Rep. New York State Cab. Nat. Hist., 1860, pp. 95, 96, 112). Meek and Worthen (this Journal, vol. XXXII, 1861, pp. 167-177) show that the Goniatite bed at this locality referred to by Hall, instead of being Marcellus, really belongs to the Carboniferous era. They claim (p. 172) that the black slate in Illinois rests upon well marked Hamilton beds and cannot therefore be equivalent to the Marcellus shale, being most probably better correlated with the Genesee as held by de Verneuil. Similarly Meek has shown that the black bituminous shale of the Athabasca and Clear Water, which rests upon a limestone stratum correlated by him with the Hamilton limestone, represents the Genesee instead of the Marcellus shale to which horizon it is referred by Sir John Richardson and Mr. Isbister. He concludes that the dark, bituminous shale or slate known as the black shale of the Western States, which is rather extensively developed in southern Indiana and portions of Illinois, Kentucky, Tennessee and some of the Western and Southern States, holds "exactly the same position with relation to the Hamilton beds as the Clear Water and Athabasca shales" and is equivalent to the Genesee shale of New York (Trans. Chicago Acad. Sci., vol. I, pt. 1, 1867, p. 65 and footnote). Similarly in Ohio (Rep. Geol. Survey Ohio, vol. I; Geol. and Pal. pt. 1, Geol. 1873, p. 154) the Huron shale is shown by Newberry to be underlain by Hamilton shales. He cites the Huron shale from Canada, New York, Pennsylvania, Kentucky, Tennessee, Michigan, and Indiana, and correlates it with the Genesee and overlying Gardeau shale of New York. In Indiana Dep. Geol. and Nat. Resources, Twenty-first Ann. Rep., 1896, p. 109, I find a chapter headed "Some notes on the Black slate or Genesee shale of New Albany, Indiana," clearly accepting Meek's correlation above referred to, while Hall and Clarke (Geol. Surv. New York, Pal., vol. VIII, pt. 1, desc. pl. 4K, fig.6) cite Lingula sp. (L. Williamsana of this paper) occurring in the black shale at Vanceburg, Kentucky, as from the Genesee horizon. These instances are enough, though others might be cited, to support the statement that the tendency among recent workers has been to concede the correlation of the black shale of the Central States with the Genesee shale of New York. And as a general statement this seems to be correct, especially when referring to the basal portion of the formation, and where, as is the case in a considerable portion of the region named, it rests upon strata of recognized Hamilton age. However, Newberry (l. c.) speaks of finding Portage fossils in the upper part of the Huron shale in Ohio (Clymenia? complanata, Chonetes speciosa, Orthoceras aciculum, Leiorhynchus quadricostatum. The last named species is characteristically Genesee, and I am at a loss to know what form is indicated by Chontes? speciosa,) Williams states (this Journal, vol. III, 1897, p. 398) that at Irvine, Kentucky, the black shale conditions continued well up into Carboniferous time, while in the vicinity of Big Stone Gap he finds the black shale resting upon a limestone full of Corniferous corals, from which he reasons that the beginning of the black shales for this region can be fixed at a horizon "closely corresponding to that of the Marcellus shale in the New York section." This would make the black shale range, locally at least, or alternately, from the age of the Marcellus shale of New York to at least that of the Kinderhook group of Illinois. A similar conclusion has been stated by Shaler, who considers this formation in Kentucky and Tennessee to include everything from the top of the Oriskany to the Chemung (Geol. Surv. Kentucky, vol. III, n. s., 18, p. 173). Lyon, however, writing in 1859 (Trans. St. Louis Acad. Sci., vol. I, p. 619-620) seems inclined on paleontologic evidence to refer the black shale of western Kentucky and Tennessee to the Lower Carboniferous rather than the Devonian, but this I believe to be due to a misapprehension on his part of the real position of the Goniatite beds at Rockford, Indiana, as included in, instead of situated above, the black shale, as is in fact the case.

Devonian-Mississippian Boundary

At the turn of the present century the problem of the Devonian-Mississippian boundary came into prominence with the work performed by Glenn (1903) in southwestern New York. Practically all subsequent work in southwestern New York, northwestern Pennsylvania, and northeastern Ohio has had to do with this question. Girty and Prosser entered the controversy from the Ohio side. In a paper by Girty (1905) entitled "The Relation of Some Carboniferous Faunas," he agreed with Herrick (1893, p. 507) that the Bedford fauna is quite distinct from any of the Waverly or Mississippian faunas, and favored placing the Mississippian (Carboniferous) boundary at the base of the Berea formation. Concerning his Bradfordian series Girty (1905, p. 7) stated that "In Ohio it (Bradfordian) is tentatively assumed to be represented by the Bedford and Cleveland shales, and probably the Erie. Its age is a matter of some diversity of opinion, but I believe that its true relations are with the Devonian." In 1912 Girty summarized his contention for a Devonian age for the Bedford in a paper entitled "Geologic age of the Bedford shale of Ohio." In it he concluded that faunally the Bedford is distinct from the underlying black shales as well as the overlying Berea fauna. In addition to the pronounced faunal change he noted that this boundary is marked by an unconformity and by a basal sandstone. Prosser did not add any new ideas to the controversy of the Devonian-Mississippian boundary. Prosser's (1905; 1912, p. 18-23, 106, and 509-529) contribution was a presentation of the conflicting opinions of others in regard to the systemic boundary.

Schuchert (1910) placed the Cleveland in his Kinderhookian series of the Mississippian system. In this classification the old Waverly grouping of Newberry was omitted. In its stead the nomenclature of the Mississippi basin was applied.

By generally accepting Newberry's classification of the Cleveland shale as the basal member of the Waverly group, Bassler (1911) and Ulrich (1911, pl. 29) indicated agreement that the Cleveland shale is Mississippian. In the same year Bassler (1911a, p. 20) included the entire Ohio shale in the Mississippian. However, this interpretation is generally regarded as a failure to consider the lower division of the Ohio shale, since Bassler presents no evidence to support the fact that the lower portion is of later age than Devonian. In 1912 Ulrich published the results of his more detailed study of the Ohio shale, in which he clarified his 1911 concept of the relation of the Ohio shale to his Chattanoogan series. In this study Ulrich (1912, p. 164) placed the Huron, Olmsted and Cleveland shales in his Chattanoogan series of the Waverlyan. His conclusions (1912, p. 158) are based on the belief that Dinichthys herzeri found in the Huron shale is not Devonian but rather "a derivative of Devonian fishes that persisted with slight modification across the systemic boundary into the initial stage of the succeeding Waverlyan system." He concurred with others that the Chagrin shale is late Devonian, which would mean by the law of superposition, that the Devonian shale (Chagrin) must underlie any younger rock (in this case the Huron shale). Ulrich contended that the Cleveland and Huron do overlap the Chagrin shale. He proposed that the Chagrin lies mainly east of Cleveland, Ohio, and originated in a sea older than and distinct from the one in which the Huron and Cleveland shales were deposited west of Cleveland. The evidence offered by Ulrich to support this hypothesis is: (1) faunal and lithologic differences between the shales of northeastern Ohio and the shales of the Huron River region, and (2) discordance in direction of dip between the Cleveland shale and the Devonian limestone at the base of the Ohio shale group.

Subsequent work by several students has cast some doubt on Ulrich's interpretation of the Sunbury-Huron black shale equivalence in Ohio to the Chattanooga black shale to the south. Kindle (1912) took issue with Ulrich's interpretation of overlapping of units. He explained variations in fauna between the units as due to bathymetric limitations of the fauna in any specific area and said that Ulrich's concept of lateral persistency of lithologies is contrary to the facts. He opposed Ulrich's overlap hypothesis of Ohio shale deposition, believing that the black shales were deposited a considerable distance from shore, whereas the lighter colored Chagrin shale represents a shallower inshore facies. Kindle concluded that the Huron underlies the Chagrin; that the faunal evidence indicates a Devonian horizon not later than Portage or Genesee for the Huron; and that both the Cleveland and the Bedford shale should be regarded as Devonian, with the Mississippian systemic boundary at the first physical break. He placed this break at the base of the Berea, which unconformably overlies the Bedford shale.

Prosser (1913, p. 359-360) and Ver Wiebe (1917, p. 47; 1917a, p. 312) concluded from their field studies of the Ohio and Pennsylvania shales that the Devonian-Mississippian contact should be placed at the top of the Bedford, which according to Ver Wiebe is Bradfordian in age. Ver Wiebe's study was based essentially on lithologic evidence rather than paleontological. Prosser based his conclusion on the evidence supported by the combination of the presence of a Devonian marine molluscan fauna in the basal portion of the Bedford shale and of an unconformable contact with the overlying Berea sandstone.

Chadwick (1925, p. 464), who regarded the "Olmsted" shale as Waverlyan (Mississippian), introduced the idea of an unconformity between his Bradfordian and Waverlyan. This unconformity caused a progressive eastward overlap (from Cuyahoga County) of the Mississippian beds (Olmsted, Cleveland, Bedford, Berea) upon the eroded Chagrin strata, and then upon the overlying Cussewago and Hayfield. From Cleveland eastward the color of the sediments becomes lighter, the sediments become coarser grained, and faunal changes take place.

Caster (1934; 1935), from his work in western Pennsylvania, has concluded that an understanding of the facies relationships of the western deposition of the Catskill sediments is essential for an understanding of the age correlations of the sedimentary units variously regarded as Devonian or Mississippian. According to Caster seven lithofacies can be defined, which characterize the variations in detrital sedimentation from the source area westward to the locus of black shale sedimentation. He named these lithofacies "Pocono," "Troga," "Catskill," "Smethport," "Big Bend," "Chagrin," and "Cleveland." The last two are present in Ohio. According to Caster the Bedford shale begins a new facies province in Ohio. Caster (1935, p. 441-442) has concluded from his field and laboratory investigations that the oldest Mississippian and youngest Devonian strata known in North America occur in northeastern Ohio and northwestern Pennsylvania. He has placed the boundary between the Mississippian and Devonian systems in western Pennsylvania at the base of the Cussewago stage of the Oil Lake series. Caster's basis for the specific demarcation is a minor hiatus and an abrupt augmentation of the last Devonian fauna by an assemblage of prenuncial Kinderhook (Mississippian) organisms. Caster (1935, p. 441-442) states:

> The setting of Cussewago deposition is essentially late Devonian; however, the faunal change in the Cussewago seems to have been engendered by a paleogeographic change which might be viewed as intersystemic diastrophism. The

reoccupancy of a late Devonian environment by the early Mississippian sea was a local condition. The latest Devonian sea occupied southwestern as well as northwestern Pennsylvania

Pepper and others (1954, p. 13-21) regard the Devonian-Mississippian systemic boundary as the base of the Bedford shale in areas underlain by black shale, and in the area of Cussewago deposition they consider the Cussewago as basal Mississippian. They have found the fauna fromthe base of the Bedford shale in the vicinity of Cleveland, Ohio, very closely allied to the fauna of the Glen Park limestone (Kinderhookian).

Pepper and his coworkers disagree with some of Chadwick's and Caster's views concerning the correlation of the controversial Devonian-Mississippian units of Ohio and Pennsylvania. This disagreement concerns the relationship of the Bedford shale to the Catskill delta. Chadwick and Caster are of the opinion that the Bedford sediments are part of the Catskill delta deposition. However, Pepper and others (1954, p. 25-27) offer evidence from their subsurface studies that the Bedford shale is separate from the Catskill delta sediments of Pennsylvania; they believe that the Bedford is a deltaic deposit whose source of sediments was in Canada.

The more recent paleontologic researchers of the age problem of these shales have limited themselves to the consideration of highly specialized and detailed study of the black shale biota, especially the microfossils. Such specialized studies include the conodonts, microflora, and the small forms of the inarticulate brachiopods present in these shales.

There is a divergence of opinion concerning reliability of these elements of the biota as indicators of age. H. J. Klepser (personal communication) is of the opinion that conodonts are facies fossils and not index fossils, and therefore cannot be used to date the age of the Ohio shale. According to G. A. Cooper of the U. S. National Museum, a brachiopod authority, lingulids cannot be used as index fossils because they have evolved slowly from the Cambrian age to recent time. The paleobotanists at present are not in agreement on the specific flora assemblage contained in the black shales, and consequently the plants alone cannot be used to determine the age of the Ohio shale. However, the specialists who have been studying the biota are of the opinion that the flora and fauna can be used to decipher the age problem once correlations with recognized units of other areas are completed.

Campbell (1946) in a paper entitled "New Albany Shale" presents the results of detailed tracing of the New Albany shale for 450 miles through Indiana, Ohio, Kentucky, and Tennessee, supplemented by a study of the reports by other geologists. Campbell's age determinations are based on a wide array of evidence drawn from every province of the geological sciences. Among these tools, Campbell (1946, p. 832-834) has utilized rock jointing as indicative of fossil assemblage changes and formational boundaries. Campbell (1946, p. 877-878) states, for example, that he "was able to delimit the Blackiston and Sanderson along Rocky River [Ohio] by means of the joints of the two beds (sec. 32)." The present author is not familiar with conditions prevailing in Campbell's section 32; however, he (Hoover, 1954) has made a detailed field and statistical study of the joint systems in the type area of Campbell's Dowelltown and Gassaway formations, which are equivalent to the Chattanooga shale of Middle Tennessee, and has concluded that joints are not indicative of formational boundaries. The author has demonstrated that individual joints pass through the Dowelltown formation into the Gassaway formation without change in attitude and suggests that more detailed work in the Rocky River region will verify the belief that joints cannot be used as formational boundary criteria.

Campbell (1946, p. 875) says the Ohio beds, Olentangy to Sunbury, inclusive, are represented in the New Albany shale. He has divided the New Albany shale into many named "formations" (some of which are not common to Ohio) ranging in age from middle Devonian to early Mississippian, inclusive. His lower Blackiston, upper Blackiston, and Sanderson are equivalent to the Huron (including the Olentangy shale), Olmsted (called upper Chagrin by others), and Cleveland, respectively. His (Campbell, 1946, p. 835, 873, and 875-880, pls. 1 and 2) definition of limits for the various members of the Devonian-Mississippian shale sequence is as follows:

<table>
<tr><th colspan="2">Age</th><th colspan="2">Indiana</th><th>Ohio
(composite)</th></tr>
<tr><td>Mississippian</td><td>Lower</td><td rowspan="3">New Albany</td><td>Upper New Albany
Underwood formation
Sanderson formation</td><td>Bedford shale
Cleveland shale (1)</td></tr>
<tr><td rowspan="2">Devonian</td><td>Upper</td><td>Blackiston formation
Upper Blackiston member
Lower Blackiston member</td><td>Olmstead shale (2)
{Huron shale and
Olentangy shale (3)</td></tr>
<tr><td>Middle</td><td>Blocher formation</td><td></td></tr>
</table>

(1) Upper stratum of Ohio shale with uniformly hard black shale.
(2) Black shale of varying hardness, gray shales, and lenses of cone-in-cone structure.
(3) Lower stratum of Ohio shale containing large calcareous concretions and intercalated layers of gray shale.

Hoskins and Cross (Hoskins and Cross, 1951a; Cross and Hoskins, 1951, 1951a) adhere to the general correlation set forth by Campbell using flora identification previously described by Read and Campbell (1939), but have found error in the identification of three genera and species of the flora, which in turn influences Campbell's 1946 stratigraphic interpretations.

Read and Campbell, in the 1939 paper, described the three genera Asteroxylon, Protolepidodendron, and Reimannia. Though these three genera have definite Devonian affinity, Read and Campbell described the shale containing them as Mississippian. Cross and Hoskins (1951a, p. 117-121) in subsequent work re-examined the Read and Campbell specimens and established the genera as Devonian which they redescribed and reassigned as follows:

Reimannia indianensis (Read and Campbell, 1939) to
Reimanniopsis indianensis (Read and Campbell) Hoskins and Cross
Asteroxylon setchelli (Read and Campbell, 1939)
to Stenokoleos setchelli (Read and Campbell) Hoskins and Cross
Protolepidendron microphyllum (Read and Campbell, 1939)
to Guycampbellia microphylla (Read and Campbell) Hoskins and Cross

W. H. Hass has voiced disagreement with Campbell's correlation of the Ohio "New Albany" shale units. Hass, a conodont expert, has studied regionally the conodonts of the Devonian-Mississippian shale sequence of Ohio and concludes from this study (Hass, 1947, p. 140-141) that "Campbell's Blackiston formation of Indiana is equivalent to the Huron shale and his upper New Albany unit is a correlate of the Sunbury shale. The Bedford shale, the Cleveland shale, and the Olmsted shale member of the Cleveland shale are younger than Campbell's Blackiston formation but older than his Sanderson formation."

G. A. Cooper and others (1942, p. 1736-1740) in the discussion of the black shales in the "Correlation of the Devonian Sedimentary Formation of North America" says:

> Portions of the black shale containing Lingulipora, Schizobolus, Styliolina, Hypothyridina, and Leiorhynchus quadricostatum are generally conceded to be of Devonian age.... In the Midwest and in Tennessee, Schizobolus has generally been assigned to the Genesee, but the presence of Hypothyridina in similar shales suggests that perhaps they should be assigned to the Tully. As both the Tully and Genesee are here placed in the Taghanic stage this

question does not greatly affect accurate correlation.

The real problem of the black shale is not with the beds carrying Schizobolus, but with the overlying strata. In general this portion has few fossils, and, except for the Kinderhookian (Hamburg) fauna at the top, has yielded no diagnostic specimens. The brachiopod Barroisella subspatulata has often been regarded as a Mississippian guide fossil, but in the New Albany shale it occurs in or near a green band not far above the Genesee equivalent which constitutes the lower 10 feet of shale. In Michigan the writer collected this species in a patch of green shale on the floor of the shale pit at Paxton, 8 miles west of Alpena, below concretions containing the Devonian goniatite Tornoceras. As this goniatite is unknown in the Mississippian, the Devonian age of Barriosella subspatulata is fixed....

When the facies relationships of the Upper Devonian are considered it would be expected that the great mass of sediments of the Appalachian geosyncline would be represented by black shales in the off-shore and pre-shelf region. Study of the Hamilton and Upper Devonian corroborates this. In northern Ohio the Chagrin shale represents the silty facies of the Conewango group and part of the Conneaut, and west of the Chagrin area, black shale appears until finally the Huron shale is thought to represent the black shale facies of the Chagrin. The Ohio shale is believed to equal the Huron and "Portage" black shale.

Passage of the Upper Devonian sediments to black shale is accompanied by thinning of the sequence.... The Upper Devonian black shales thin to the west, except locally, but it cannot yet be proved whether the outlying strata equal all the Upper Devonian or whether there is overlap. In the latter case the beds farthest out would be youngest....

Although direct fossil evidence of the age of the black shales has not yet been found the presence in a number of areas of a basal Kinderhook fauna gives a definite upper limit to the Devonian shale. The fauna in question is that of the Hamburg oolite that occurs in the Glen Park limestone in Calhoun County, Illinois.... To the east it has been seen at the top of the New Albany shale (Huddle, 1933) and it occurs also in the Bedford shale of Ohio. Foerste (1909) traced the Bedford fauna into eastern Kentucky. Savage and Sutton (1931) report it in south-central Kentucky, and J. H. Swartz (1924) describes it at Eulie, Summer County, central Tennessee....

The Devonian or Mississippian age of the Hamburg fauna has not yet been settled. Although originally described as Mississippian (Weller, 1906) a Devonian age was claimed by Girty (1912) for its equivalent in the Bedford shale. More recently Branson and Mehl (1938) and Branson (1938) champion the Devonian claim. The majority of the species do have unmistakable Devonian affinities and include some familiar types: Nucleospira and Atrypa of the brachiopods and Modiomorpha, Sphenotus and Cypricardella of the pelecypods. In a long list of Devonian forms the few Mississippian elements are Syringothyris (not always Mississippian), Spirifer marionensis, and Goniatites. Total absence of true productids is significant. At present the fossils have not been sufficiently well studied or illustrated to date the beds definitely. Should the fauna prove to be Devonian the black shales will be Devonian; but if the age remains Mississippian, as it is by definition, the lower Kinderhook being part of the type Mississippian, the fauna will serve as an excellent ceiling for the Upper Devonian.

In the South the age of the Chattanooga has been scrutinized by J. H. Swartz (1924).... According to Swartz the shale below the Bedford-Berea is of Cleveland age, here assigned to the Devonian....

In summary it may be said that according to the writer's view most of the black shale discussed in the Midwest and Appalachian region represents a black shale facies of the Upper Devonian underlying a fauna of highest Upper Devonian or basal Kinderhookian age. These black shales may represent the feather edge of the thinning Upper Devonian, thickening locally on the flank of the Cincinnati arch as shown by Caster (1934) in the case of the Cleveland shale. Furthermore the Bedford Hamburg shows a facies change in harmony with that of the Devonian--i. e., shale in Ohio and Indiana and limestone in Illinois and Missouri.

In the "Correlation of the Mississippian Formations of North America" (Weller, 1948, p. 102-104), C. L. Cooper summarizes the evidence in support of the dating of the black shales as Mississippian in age as follows:

"Three different conodont zones were recognized by Huddle in the New Albany shale of Indiana.... The lowest zone yielded a fauna similar to assemblages known from the Upper Devonian of New York (Genundewa and Rhinestreet). These or closely related beds at various places also contain Lingulipora, Styliolina, Hypothyridina, Schizobolus, Leiorhynchus quadricostatum, Tornoceras, and Spathiocaris cushingi....

"Near the top of the upper New Albany is a thin, possibly local, gray shale (Underwood) which contains a small brachiopod fauna suggesting a correlation with... the Bedford shale of Ohio and eastern Kentucky....

"At or near the top of the New Albany is a zone of peculiar small phosphatic concretions (Falling Run) that is persistent throughout southern Indiana and has been traced southward into Kentucky and Tennessee.... Some of these concretions contain specimens of Spathiocaris williamsi and other crustaceans which are known... (from) the Cleveland shale of northern Ohio....

"The conodonts of the upper New Albany zone are similar to those present in the Cleveland and Sunbury shales of Ohio.... These beds are now generally conceded to be Mississippian.

"Thus it appears that the boundary between the Devonian and Mississippian systems occurs within the New Albany shale and its equivalent elsewhere. Although unconformities in the midst of the black shale have been reported..., no breaks in this sequence are obvious at most places, and lithologic similarity of Devonian strata below and Mississippian strata above makes any division difficult. Also it is as yet uncertain whether the middle New Albany conodont zone should be referred to the Devonian or Mississippian.

"This middle zone has generally been considered Devonian in states east of the Mississippi River, but its equivalent, the Grassy Creek shale, in northeastern Missouri and western Illinois has generally been regarded as the basal formation of the Mississippian Kinderhookian group or series. Branson and Mehl, however, state that the conodonts of the Grassy Creek shale are unmistakably Devonian, and because of the close stratigraphic relationships of the Grassy Creek and Saverton shales (they recognize only a single formation) and the Louisiana limestone, they place the Devonian-Mississippian boundary at the base of the Hannibal shale. They base their conclusion that the Grassy Creek fauna is Devonian principally on the occurrence of the conodont genera 1) Polylophodonta, 2) Ancyrognathus, 3) Palmatolepis, 4) Apatognathus, 5) Nothognathella, and 6) Icriodus.... So far as is known at present, all but the first and fourth genera occur in undoubtedly Devonian strata. The first genus is known only in beds of middle New Albany age and the third and sixth are present in upper New Albany or younger strata. The second and fourth genera possibly persist into younger than any of the New Albany. Thus the known ranges of these genera favor the Devonian assignment of the Grassy Creek (and therefore the middle New Albany) only slightly. Considered on the basis of the complete conodont fauna, however, a Mississippian age of the Grassy Creek shale appears more probable because 16 species range upward against only 2 which range downward. Figures for the middle New Albany fauna are almost the same, with 17 species persisting into younger beds and only 2 carrying over from the undoubted Devonian. These figures, however, may be somewhat misleading because the undoubtedly Devonian fauna of the lower New Albany contains 6 species that persist into upper New Albany or younger beds and only 2 that are exclusively Devonian."

Much paleobotanical work has been performed on various portions of the Devonian-Mississippian shale sequence by J. Schopf and M. R. Winslow of the U. S. Geological Survey. Most of their work is still in the manuscript stage, but an Ohio State University Master of Science thesis covering work performed by Winslow (1954) describes many new paleobotanical species which she feels provide new evidence for future stratigraphic correlation.

PALEOECOLOGY

Paleoecology is the study of ancient organisms or communities of organisms in relation to their inorganic and organic environment. Despite its geologic affiliations, paleoecology rests on biologic concepts, because fossils are the remains of, and therefore the representatives of, formerly living organisms, and not merely physical constituents of sediments. Of the biologic concepts, two may be specified as essential with regard to the method of study, namely the physiologic (autecologic) and sociologic (synecologic) concepts. The characteristics of paleoecology are such that it must be chiefly descriptive--it must place emphasis on the ecology of the individual (autecology) and its historical scope. Paleoecology combines biologic data with paleontologic and geologic data and methods. Though this science is primarily concerned with the sociology of fossil organisms, it is organized on biologic facts of morphology, anatomy, physiology, stratigraphic paleontology, and taxonomy, as well as on the geologic data of stratigraphy and sedimentology.

The ecological aspects of the Ohio Devonian-Mississippian shales have not been favorable grounds for areal study by the paleoecologist. However, the paleoecological aspects of the Devonian portion of these shales have been investigated in the Columbus region by J. W. Wells (1947) and published in a paper entitled "Provisional paleoecological analysis of the Devonian rocks of the Columbus region." In this paper his paleoecological findings are described under two shale lithotopes, which he called his "dark shale lithotopes" and "light shale lithotopes," respectively. Wells (1947, p. 124-126) summarized his investigations as follows:

Dark shale lithotope:

These are exemplified by the Ohio shale and the "Dublin shale" shale phase of Zone I of the Delaware, and are essentially nearly unfossiliferous bituminous shales.... Both are lithotopes indicative of brackish-water environments; both contain analogous thanatocoenoses of a few species of thin-shelled brachiopods (Leiorhynchus, Lingula, and Orbiculoidea) with occasional euryhaline wanderers. Lingula, a mobile form, lived in muddy bottoms, the others were sessile and probably fixed to seaweed. Conditions were quite impossible for other groups such as corals, crinoids, trilobites, cephalopods, etc. They were less rigorous in the Dublin shale biotope than in that of the Ohio shale, where the blackness of the deposit with much pyrite indicates foul water with very low oxygen content.... In the Ohio they are very scarce, and significant only in the Bellefontaine outlier some 50 miles to the west of the Columbus region, nearer the old shore of Cincinnatia. Here there are several layers near the base of the formation crowded with individuals of Lingula, Orbiculoidea, Leiorhynchus and Chonetes, together with the vast number of Styliolina. The last may represent pelagic dwellers in the better-aerated surface waters. The fish remains of the Ohio, like those of the middle Devonian limestones, are not those of endemic marine forms, but remains of stray carcasses drifted in from the streams of Cincinnatia. The same origin also applies to the occasional plant remains in Ohio. Some of the silicified logs of Callixylon bear traces of attached or entangled crinoids (Melocrinus) that they bore while floating at the surface of the foul-bottomed sea....

Light shale lithotope:

The Olentangy shale, a slightly calcareous gray-green clayey shale with thin layers of impure limestone, is nearly unfossiliferous. Fossils, except for microscopic forms (ostracods, conodonts, and plant remains), are found almost exclusively in the nodular pyritiferous limestones. The presence of one or two thin layers of black shale in the Olentangy and of occasional layers of green shale in the lower part of the Ohio shale suggests that the Olentangy is a basal phase of the Ohio. Its thanatocoenose consists of a very few forms indicative, not of brackish-water biotope of the Ohio, but a very impoverished nearly normally saline but uncongenial biotope; one or two small rugose corals, a few bryozoans, several tolerant brachiopods (Lingula, Chonetes, Ambocoelina) and orthoconic nautiloid, and goniatites (Tornoceras and Manticoceras) and a few others. Neither species nor individuals are abundant. Seemingly this was a depauperate biocoenose of the normal benthonic type eking out a ragged existence against stifling fine muds, most of the time driven out by mud, returning during the brief intervals of reasonably clear water represented by the thin limestones. Occasional crinoid plantations did exist, notably the one at the type locality of the shale near Delaware--a lens several inches thick of comminuted remains of the large Melocrinus bainbridgensis, a species also found in the green layers near the base of the Ohio shale and the probable pseudobenthonic associate of the Callixylon logs of that formation.

Summary paleoecological analysis of lithotopes....
Light shale lithotope: slightly calcareous green-gray shale with thin layer of impure, pyritiferous limestone.
Biotope: normal saline, warm, but very muddy water below wave base, subnormal oxygen content.
Biocoenose (thanatocoenose): depauperate, multi-layered society, species and individuals few.
Distribution: Olentangy shale.
Dark shale lithotope: brown to black, often pyritiferous, bituminous shale.
Biotope: brackish water, often foul and poorly aerated except superficially, muddy, below wave base.
Biocoenose (thanatocoenose): few species of thin-shelled types, with individuals locally numerous, forming two or three layer societies, (surface, on bottom, and in bottom).
Distribution: Ohio shale and locally in Zone I of Delaware formation

Since the rock type of the Devonian-Mississippian shales in other portions of Ohio is similar to that of the Columbus region, it should not be expected that the paleoecology of the Olentangy or the Ohio shale (or its divisions) should show marked variations in other portions of Ohio. The author has seen layers, both vertically and laterally, in the Ohio shale containing a profusion of Lingula and Orbiculoidea. This suggests that such layers represent local shorelines, and that the shales were deposited in a sea that was transgressing or regressing, and the relation of the strandline to the boundaries of Cincinnatia was ever changing.

There are no published papers on the paleoecology of the Bedford shale or the northern equivalents of the Olentangy shale. Lithologic and fossil criteria suggest that the paleoecology of the Plum Brook shale should be similar to that of the Olentangy shale. That of the Prout limestone, Silica shale, and Ten Mile Creek dolomite should have some characteristics of a light shale lithotope as well as those of the normal and impure limestone lithotopes as outlined by J. W. Wells (1947, p. 125-126) for the Columbus and Delaware limestones of central Ohio. The paleoecology of the Bedford shale might be expected to be more complex than that of the underlying units. The depositional conditions of its sedimentation, according to Pepper and others (1954), display the characteristics of deltaic environment with the sediments being deposited both subaerially and subaqueously. The paleoecological criteria would be characteristic of argillaceous and clastic sediments, a marine and fresh water fauna tolerant to saline waters, etc.

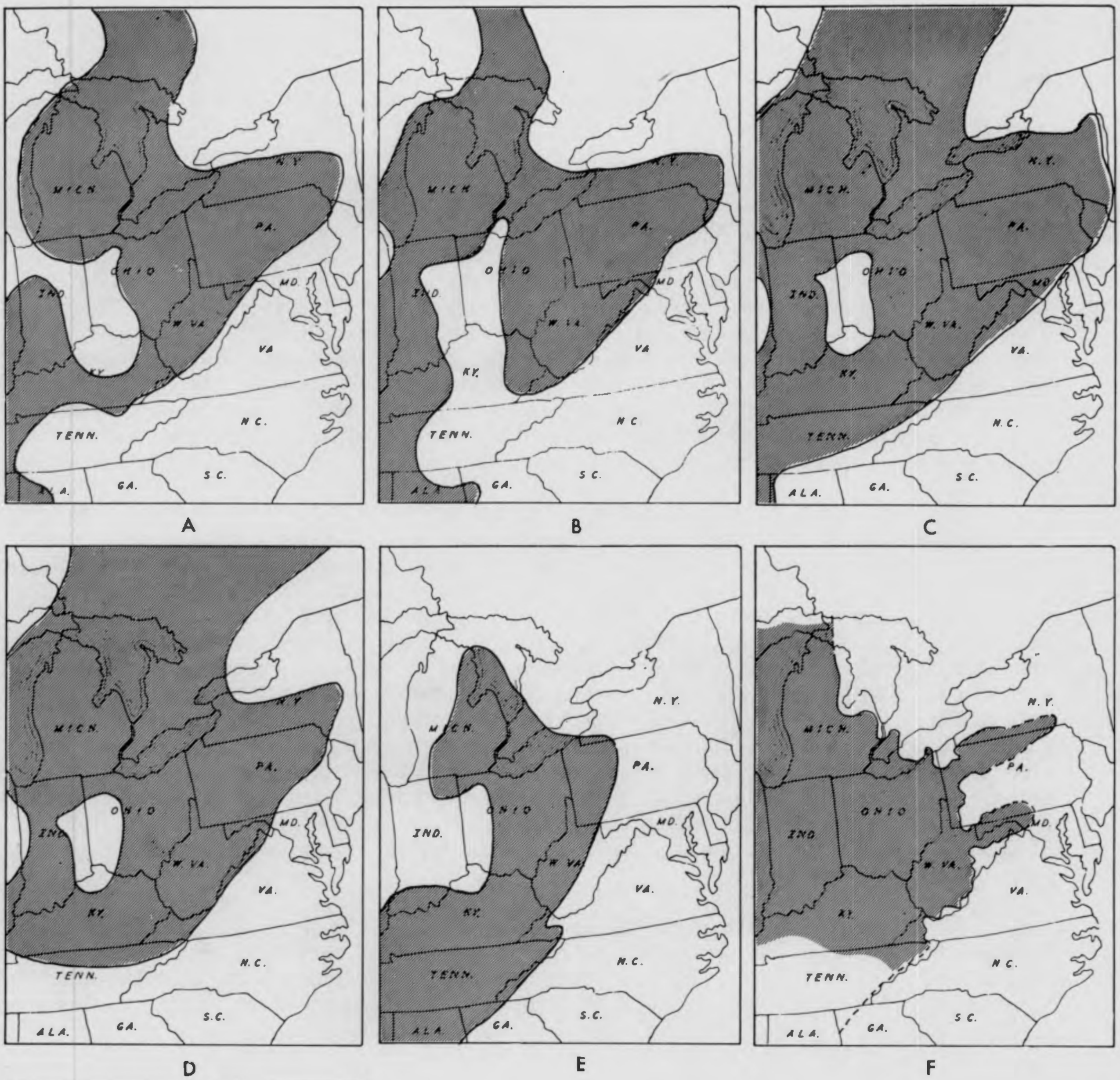
PALEOGEOGRAPHY

Paleogeography treats of ancient or geologic geography, the word having been first used by the English paleontologist Robert Etheridge, in his presidential address before the Geological Society of London in 1881. Paleogeographic maps, however, were made long before the word was originated, the first one having been constructed in 1863 by J. D. Dana. It was not until 1910, when Schuchert published his concepts on the paleogeography of North America, that the study of past geography came to the forefront. Since that time a great number of such maps have been published.

To understand the various ancient invasions of the seas into Ohio, it is necessary to know the connections with marine waters that at different times have flooded the North American continent. The marine waters that have invaded Ohio are extensions of the oceans which encroached upon the land as continental seas. Collectively these bodies of water which covered Ohio are referred to as the Appalachian Sea of Paleozoic age; and that portion in which the Devonian-Mississippian shales were deposited is called the Ohio Basin Sea (Schuchert, 1910, p. 48). These seas covered depositional basins called geosynclines. The geosynclines in which the Ohio Devonian-Mississippian shale sequence was deposited are named the Appalachian geosyncline and Michigan basin. Into these depositional basins, the streams unloaded sediments which accumulated to thicknesses in excess of 3, 500 feet and which now form the Devonian-Mississippian shales. At no time was the Appalachian Sea a deep sea, certainly not in the sense that the Atlantic Ocean is deep; instead it was a basin that slowly subsided under sediment loading, and thus maintained a fairly constant depth. During Bedford time these basins were nearly filled by detrital materials.

It long has been known that the Devonian succession and faunas vary greatly in different regions of North America. These differences result from isolation and different oceanic connections. To discover these connections is chiefly the work of the paleontologist, as the record to be deciphered is derived mainly from study and analysis of fossil assemblages.

An examination of Schuchert's paleogeographic maps (1910; 1955) of the uppermost Middle Devonian to the lowermost Lower Mississippian shows that the Appalachian Sea during part of that time had two connections with the Atlantic Ocean, but for most of the time only one. Since the 1955 set of Schuchert's paleogeographic maps include many refinements of the 1910 edition, discussion will center around Schuchert's later work and figure 8 of this paper. During deposition of the Olentangy shale and its northern equivalents, as well as the basal beds of the Huron shale, the Appalachian Sea had two connections with the Atlantic Ocean. In the north, this continental sea was connected with the Atlantic Ocean by means of the St. Lawrence Sea; to the south it opened into the Mexico Mediterranean. According to Schuchert (1955, pl. 38 and 39) the southern opening was severed after deposition of the basal Huron beds, and during the remainder of the Huron shale sedimentation and all of the Chagrin, the Ohio region was connected with the open ocean only through the St. Lawrence trough. Connection with the gulf coast area was renewed during deposition of the Cleveland and Bedford shales.



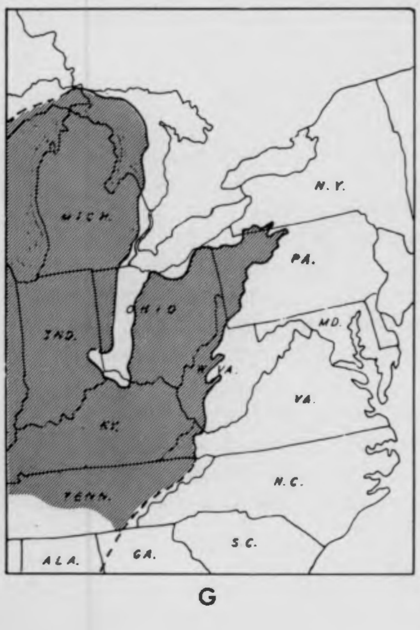


Figure 8. - Paleogeographic maps of the Ohio region during part of the Devonian-Mississippian time. Shading indicates areas covered by marine water during the time shown.

A. Columbus-Delaware limestone time (Onondagan)
B. Olentangy-Plum Brook-Prout-Silica-Ten Mile Creek time
C. Huron shale time
D. Chagrin shale time
E. Cleveland shale time
F. Bedford shale time
G. Berea sandstone time

Modified After:
Pepper, J. and others. 1954, Plate 13-A, B, C, D, &E
Schuchert, C., 1923, Figs. 8 & 9
Schuchert, C., 1955, Maps 35, 37, 38, 39, 40
Stauffer, C., 1909, Plates 14 & 15
Weller, S., 1895, p. 905
Williams, H., 1897, p. 395
Willis, B., 1909, p. 287-288

During all the deposition of the Ohio Devonian-Mississippian shale sequence most of Ohio remained submerged. Paleogeographic studies indicate that only parts of the southwestern portion of the State remained as positive (exposed) land during this time. Undoubtedly the shoreline changed from time to time so that parts of the southwestern portion of the State were receiving sediments while others were islands along the Cincinnati arch.

Because of preglacial erosion and present glacial cover of much of the Cincinnati arch region, many moot questions remain concerning sedimentation across the arch. Much of our knowledge concerning the depositional history here is gleaned from exposures on the Bellefontaine outlier, which lies near the present axis of the Cincinnati arch. Outcrops on this outlier reveal the presence of that part of the Ohio shale recognized lithologically as the Huron and Cleveland shales. Here the Ohio shale rests directly on the Columbus limestone. The absence of both the Delaware limestone and Olentangy shale indicates that this portion of the Cincinnati arch was positive land during deposition of these rock units eastward in the Appalachian geosyncline, but that it was inundated during at least most of the Ohio shale (proper) deposition. Whether the Bedford shale was once present here is not specifically known, but from the paleogeographic setting of the Bedford shale worked out by Pepper and others (1954, p. 95-104) it seems plausible that Bedford sedimentation did not extend this far west.

The sediments deposited in the Appalachian geosyncline during much of the Paleozoic time apparently were derived for the most part from land to the east and southeast. This seems to be true for the Olentangy, Huron, and Cleveland shales. The northern equivalents of the Olentangy are not well understood, but it seems reasonable from the dissimilar biota that the Olentangy shale sediments are allied with the Mexico Mediterranean connection, whereas the Plum Brook shale, Prout limestone, Silica shale, and Ten Mile Creek dolomite are intimately associated with the St. Lawrence prong of the Appalachian Sea. Winslow (1954, p. 10) says DeWitt proposed a southwestern deposition direction for the Chagrin shale. Winslow (1954, p. 90) believes the source area for the organic constituents of the black shales could have been from the west, north, and east, or the organic matter could have been derived from partial decomposition of marine algae. The deposition of sediments along the eastern border of the geosyncline tended to shift the geosynclinal axis westward throughout the Devonian, but eastward again during Early Mississippian time (Pepper and others, 1954, p. 95, fig. 58). During Bedford shale deposition a greater part of the sediments were derived from the north.

Part of the sediments in the Michigan basin may have been derived from the east and the rest from the north and northwest. So little has been published pertaining to the Ohio geology of the Michigan basin that an understanding of the relationships of the Ohio Devonian-Mississippian formations with those in Michigan must await future investigations of this area.

STRUCTURE

REGIONAL

The geologic structure of Ohio may seem to the casual observer to be simple and almost monotonous. But on more careful examination the structure is found to be locally diversified in the position the strata occupy relative to each other and to the horizontal. Although there are no conspicuous arches or dislocations of the strata, geological structural mapping reveals a series of undulations or folds, the magnitude of which is masked by erosion of the surface and by superficial materials which generally conceal the underlying rocks.

The largest fold in Ohio is the north-plunging portion of the Cincinnati arch, called the Findlay arch. It is a broad low fold, with the formations dipping away from the axis into the Appalachian geosyncline to the east, into the Michigan basin to the west, and gently northward parallel to the crest. The anticlinal axis and geosynclinal axis extend northeast-southwest; however, the latter strikes somewhat more to the east than the former. The northern and more shallow part of the trough, therefore, is relatively farther east, and as a result there is practically no east dip across the northeast part of Ohio. In that section of the State the dip is principally to the south. (See structural contour map, pl. 2.) The general (regional) dip is southeast, and the average rate of dip is 30 to 40 feet to the mile (or 35 feet for the Devonian-Mississippian shale sequence.) There is evidence that the Cincinnati arch was in existence in Late Cambrian time. Upper Ordovician beds are exposed around Cincinnati, Ohio, but certain younger stratigraphic formations were deposited over the arch, apparently with diminished thickness. Some geologists favor the view that Mississippian rock once covered the arch, but no vestige of Mississippian rock remains as evidence to support this thesis. At least 120 feet of Ohio shale is present in Logan County, which suggests that it was either deposited across or very close to the top of the Cincinnati arch. Although the Cincinnati arch is the only major structural feature of western Ohio, there are a number of major features common to eastern Ohio. Ver Steeg (1944, p. 132, fig. 1) lists them, from west to east, as follows: the Rutland terrace, the Amesville terrace, the Parkersburg-Lorain syncline, and the Cambridge arch. All of these features have a trend of about N. 10°W. which, according to Ver Steeg, is approximately the same as the strike of the majority of the faults in Ohio. East of the Cambridge arch the normal east dip of the formations is broken by minor structures which have a northwest-southeast trend. The axes of the minor structures do not parallel the major structures except in the northern part of the coal-bearing area. In southeastern Ohio the trend of the minor structures is nearly normal to that of the major structures. The major structures are not parallel with the Appalachian folds, nor are they in line with those of the Michigan basin.

LOCAL

A study of the structure-contour map on top of the shale series (pl. 2) shows that the regional structure is modified by certain minor structures; most conspicuous among these are structural terraces and structural noses.

Structural Terraces

Structural terraces are developed in areas where dipping strata locally assume a horizontal attitude and produce a very faint anticlinal fold parallel to the general strike of the region. The effect of such slight folding of inclined strata is to steepen the regional dip on the down-dip side of the faint anticline (thus producing the terrace front) and to decrease the regional dip on the up-dip side of the anticline (which in turn forms the terrace flat).

These structural terraces of the Bedford shale, though rather ill defined, are limited to the northern portion of the State where this shale has a general east-west strike. The relationship of these terraces seems to be more allied with the depositional history of the shale sequence than with any tectonic origin. Thickness studies of the Bedford shale by Pepper and others (1954) reveal that the Red Bedford delta is thicker in northern Ohio, near the source of the sediments. From such a study it might be suggested that, passing northward, the sediments were deposited stepwise upon a comparatively stable basement in that portion of Ohio in which the strike of the Bedford is essentially east-west. If such conditions prevailed, the deltaic sediments would no doubt be deposited as terraces. In that portion of Ohio underlain by the Bedford shale in which the strike is northeast-southwest, terraces might not have developed because of a constant rate of subsidence and thinning of the Bedford sediments.

Structural Noses

A second irregularity of regional structure in the Bedford shale is shown on the structural map (pl. 2) by local projections or loops of contours with their convex side generally pointing to the south and southeast in the down-dip direction. These are local half domes on the regional dip and are called noses. They show especially on terrace fronts and are inconspicuous on the terrace flats. The structural origin of these noses is not clear. No doubt some are due to faint anticlinal folds but perhaps most are physiographic expression of the fluvial pattern at the outset of Berea sedimentation.

SPECIAL FEATURES

Primary (Mechanical) Features

Flow Structures

A frequent type of deformation is the intricate folding and contortion of the beds of the Bedford shale (flow rolls, fig. 7). These gravitational folding phenomena are preserved in several different forms and are thought to be due to submarine slumping. Fairbridge (1946, p. 84-92) says the general form of these submarine structures is twofold, namely, "intercalated, intraformational contorted zones, wedged between parallel undisturbed strata," and "sedimentary, intraformational breccias and conglomerates." Both forms and all their modifications are present in the Bedford shale. The disturbed rocks are composed of the same lithological types as normal rocks and are found showing varying degrees of disturbance stratigraphically and laterally. In the most disturbed rocks the bedding planes are folded or corrugated or minutely crumpled with small rock masses, differing in structure from each other, piled one upon another to produce small-scale nappes. In other places, the rocks are intensely contorted, as though the sediments had been violently stirred while still in a pasty condition. Masses of highly contorted muds from a few inches to several feet in diameter are "balled up" somewhat in the manner of a snowball and lie isolated in other muds. In some examples muds are seen to have been injected into siltstones as "sandstone dikes". The dips and strikes in these masses are exceedingly variable and seem to bear no relation to those of the normal sediments which underlie or overlie them.

Many geologists have observed these features in the field (Prosser, 1901, 1912; Prosser and Cumings, 1904; Carney, 1909; Cooper, 1943; Nelson, 1955). Nelson (1955, p. 25-27) observed these structures in his Rocky River and Sinner's Run sections. He is of the opinion that these structures are related to the Cleveland interval in a "formational" sense because black beds are present above the contorted mudrock bodies. Hyde (1953, p. 30, 41-49) notes the "mechanical movement" to which various horizons of the Bedford shale were subjected in southern Ohio; he describes them at length and postulates an origin for them. Pepper and others (1954, p. 22) refer to these distorted siltstone beds in the Bedford (basal beds) of northern Ohio as "flow rolls" and the zone of deformation as the "flow-roll zone." Hyde (1953, p. 41) says these structures of contorted bedding have their greatest development in central Ohio and that they are best developed in those portions of the formation in which shale and sandstone alternate, but he has observed instances in which only one type of rock is involved. Hyde reports that areally any zone subject to contortion may be entirely normal for 10 to 20 yards or more, with only occasional intervals of disturbance; and that a zone of contortion may involve three or more independent beds and be as much as 3 or 4 feet thick but never less than 4 inches. Cooper (1943, p. 193) has observed disturbed rocks 120 feet across and at least 25 feet deep involving the Bedford and the lower part of the Berea.

Explanations concerning the method of formation of these contorted structures are varied. Prosser (1901 , p. 217, and Prosser and Cumings, 1904, p. 340) postulated a concretionary origin; Orton (1878, p. 640) suggested that they represent "masses of mud to which a rolling motion had been given before they were solidified"; Carney (1909, p. 142) and Cooper (1943, p. 198-203) attributed them to "contemporaneous slumping of mud sediments." Hyde (1953, p. 45-49), though not entirely satisfied with the explanation he advanced, concluded that:

> ...If the soft mud beneath the sand, should be extruded locally, due to some unknown conditions which overbalanced the equilibrium maintained elsewhere, if they should flow out allowing the sands to settle gradually into their place, the result would be just such a structure as is here found....
>
> ...It is believed that this flowage took place in each bed or sometimes in two or three beds independently of the flowage in the other beds and before any very great amount of material, perhaps only a few inches, had accumulated over it.

Pepper and others (1954, p. 89) believe the formation of these features depends more upon the horizontal flowage of sediments (in response to either unequal loading of softer substratum or unequal unloading of more mobile substratum of mud) than to the initial slope of the surface upon which the sediments were deposited.

The conditions under which sliding might be expected to take place on a subaqueous slope have been discussed by various authors in light of modern submarine observations (Kuenen, 1950, p. 500-501; Shepard, 1948, p. 195-198, 240, 309; Shepard, 1951, p. 405-418; Trask, 1939). Hadding (1932, p. 377) in a paper entitled "On Subaqueous Slides" enumerates the conditions which would a priori render sliding possible. Sediments accumulating an a subaqueous slope would slide or slump if the weight increased beyond a certain amount for a given slope, or if the slope became steeper, or if support was removed lower down the slope, or under the influence of an external impulse such as movements in the water or an earthquake shock. Hadding also points that the frictional resistance to sliding on a surface within a mass of uncemented sediment is, in general, less than on a surface between sediments and a solid rock floor.

Ripple Marks

Many investigators have reported ripple marks in the Bedford shale (fig. 9). Because of the fineness of grain of the mudstones underlying the Bedford, few workers have noted ripple marks in them. Nelson (1955, p. 28) has observed current bedding, crossbedding, and ripple-marked beds in the Chagrin shale and Trumbull facies in the "Cleveland horizon" of northern Ohio. He reports that these features become more common toward the eastern edge of the outcrop in direct ratio to the increase in silt and sand content of the Chagrin shale.

Ripple marks are a conspicuous feature of the Bedford shale. The ripple crests are usually less than 1 inch high and are generally 3 to 5 inches apart. Most of these ripple marks are of the oscillation type characterized by symmetric profile, relatively narrow sharp crest, and broad shallow concave troughs.

According to Hyde (1911, p. 263), no examples of current-ripple type caused by strong currents of water moving in one direction have been observed in the Bedford shale. Pepper and others (1954, p. 82, fig. 49, p. 84-88) report the presence of current-ripple and interference-ripple marks. Though the current-ripple marks are not abundant they are scattered throughout the State, whereas the interference-ripple marks are limited to the northern portion.

The best formed ripple marks are found in southern Ohio. Here they are limited to

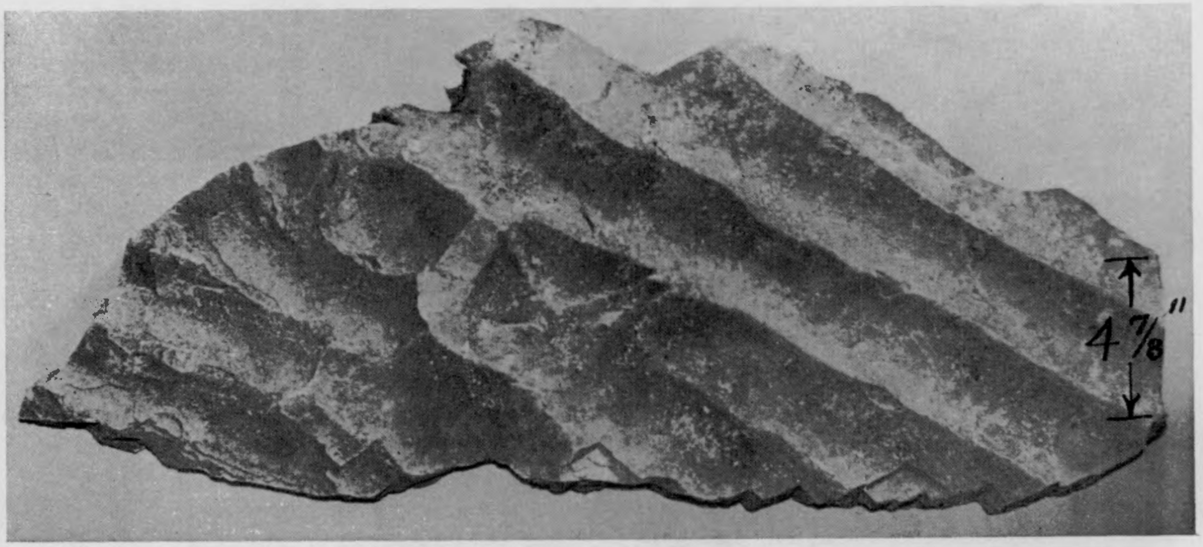


Figure 9. - Ripple marks in the Bedford shale. Rock collected along Ganderhook Creek, Pike County, Ohio.

the upper portion of the Bedford, where lithologically it is generally a siltstone. In central Ohio, ripple marks decrease in number because of the decrease in the siltstone content. In northern Ohio the thin gray siltstone and sandstone that occur at the base of the Bedford contain oscillation-type ripple marks. Although the red Bedford shale, which was deposited largely subaerially, is devoid of ripple marks, the silty gray Bedford shale that was deposited east of the red Bedford shale contains an abundance of oscillation-ripple marks.

In southern Ohio the ripple marks have a relatively constant crestal trend; the average trend is about N. 60°W., with a maximum deviation of 35° (Pepper and others, 1954, p. 79). Hyde (1911, p. 269) reports that in central Ohio the great majority range between N. 40°W. and N. 55°W. The oscillation-ripple marks are very erratic in northeastern Ohio. The trend of the ripple crests in subjacent beds may vary as much as 90°.

In northeastern Ohio Pepper (1954, p. 81) found that the ripple marks are smaller than those observed elsewhere in the State and that the crests tend to branch or bifurcate in the manner of current-ripple marks.

Hyde (1911) concluded that the general parallelism of the ripple trends in southern and central Ohio was due to the control exerted by shallow waters close to an existing shoreline or shoal water areas. He postulated that a land mass existed which extended northwestward across eastern Kentucky and abutted against the Cincinnati arch in southern Ohio. Bucher (1919, p. 249-269) and Pepper and others (1954, p. 81-88) concluded that the cause of the constancy of ripple-mark trend in southern and central Ohio was climatological control rather than a shoreline control as advocated by Hyde. Data collected by Bucher indicated that the ripple marks formed in an elongate basin which was so shaped as to permit the greatest action of ripple-producing winds only from the northeast or southwest; therefore he ascribed the formation of the ripples to winds either blowing strongest from these directions or having the greatest fetch in these directions. Pepper's field evidence of parallelism of ripple marks in northern Ohio was inclusive.

The literature noticeably lacks reference to mechanical structures in the shales underlying the Bedford shale--so much so as to imply that these muds were deposited as a monotonous mass. But the work of Nelson (1955) suggests that detailed field observations of these shales will produce abundant examples of such mechanical structures. Nelson (1955, p. 28) reports on his reconnaissance study of current bedding, crossbedding, and ripple marks observed in the Chagrin shale as follows:

...In the gorge of Trumbull Creek the upper beds of the Chagrin occasionally show strong cross-bedding that has an amplitude of ten to twelve inches. This cross-bedding dips towards the east. The trends of ripple-marks and current bedding have not been examined in detail, but they appear not to show pronounced directional character.

Texturally the Chagrin is perhaps more susceptible to development and preservation of such structures, but diligent fieldwork may reveal such structures in the other units.

Shrinkage Cracks

The bedding surfaces at various horizons of the Ohio shale exhibit irregular cracks enclosing convex polygons. These irregularly checkered polygonal patterns are called mud cracks or shrinkage cracks. The polygons range from 2 inches to 2 feet in diameter, but the average is 10 inches. They usually range from less than 2 to as much as 8 inches in thickness. The surfaces are irregularly warped and the edges are sharply downwarped. Many of the edges seem to have been drawn out (taffy fashion) to develop the depression between polygons rather than having been broken or torn away from the neighboring polygons. Other polygons are separated by a visible crack, though the gap is usually only a millimeter in width. Though the polygons are irregular in shape, the homogeneity of the muds is considered to control their uniformity in size. Except for tiny nodules that form from segregation of mineral matter, the polygons apparently are devoid of lamination or other structures.

There are several suggested explanations for the development of these mud cracks. Though it is highly probable that they are subaqueous in origin, the interpretation that they were subaerial (postaqueous) in development can not be ruled out until more knowledge is gathered concerning the environment of deposition and the depth of water in which the muds were deposited. The most conspicuous feature distinguishing subaqueously from subaerially developed shrinkage cracks is the direction of curvature of the polygons. The subaerial polygons are concave downward while the subaqueous polygons are convex upward; and since it is generally thought that the black muds were never subaerially exposed it seems quite logical that these cracks originated beneath the water.

Several methods for the subaqueous origin of these features are possible. They may have arisen from freezing in the manner described by Moore (1914, p. 101-102).for mud cracks which developed in a 1-foot deep fresh-water pond. Moore thought they were due to the ground freezing, and expanding, and later thawing and contracting. It is highly probable that the mud cracks in the Ohio shale could be due to freezing and thawing action. Because the black muds were deposited in saline water, cold climatic conditions would necessarily have been of a sufficient duration to freeze the water as well as the underlying muds to the needed depth to develop the cracks. If climatic conditions prevailed long enough for this to occur it would suggest that varved beds should be associated at least with the overlying layers. A criterion in favor of this theory is that the sediments, plus overlying layers, in which these features are very frequently found, are lighter in color than true "black shale" beds.

Twenhofel (1925, p. 75-76) observed cracks in muds which had a high bentonite content and which had developed in the bottom of a lake in the Big Horn Mountains. He experimentally produced these features in bentonite and powdered hematite sediments without their exposure to the atmosphere (Twenhofel, 1923, p. 64; 1925, p. 75-76). Twenhofel concluded from his experiments that the cracking was due to differential water absorption and swelling of the bentonite. He believed that due to the coherence of the bentonite particles the saturated surface particles offered protection to the inner portions. However, our mineralogical knowledge concerning the components of the polygon masses is not complete enough to suggest that bentonite would be present in great enough quantities to produce these features. Furthermore, if these muds were deposited as slowly as many proponents suggest, any one layer of sediment would be sufficiently thin and thus subjected to water for such a long span of time that full expansion of the bentonite particles would take place before sufficient thickness could accumulate to produce the bulges observed as mud-crack polygons.

Experiments by Kindle (1917, p. 135-144) showed that convex mud cracks develop in saline-water mud. Bradley (1933, p. 55-71) concluded from his field observations and laboratory experiments that the shrinkage capacity and cohesiveness of the muds are directly related to the clayey, flakelike particles in the muds. He says that the polygonal plates tend to become convex toward the coarser grained material and that the amount of curvature varies directly as the grain-size gradient. Bradley contends that salt-crystal growth in the upper layers coarsens these layers with respect to the lower layers (inversion of the normal order of grain-size gradient). Because these conditions are considered to have prevailed in the black muds the mud cracks in the Ohio shale could have originated in this fashion.

Pit and Mound Structures

Many surfaces of the shale laminae are strewn with elliptical markings surrounded by a raised ring within which is a sunken annular area attached to a descending conical column. These are usually only a few millimeters in diameter and show no recognizable arrangement over the surface of the rock. These structures are frequently filled by pyrite, the casts of which resemble little blobs the size of shot, with tapering tails.

Three schools of thought prevail concerning the origin of this type of structure. C. D. Walcott (1899, p. 231) thought such structures represented Aspidella sp., a so-called fossil described by Billings from the Precambrian of Newfoundland. Most examples of pit-like structures have been interpreted as representing impressions made by falling substances. Some investigators believe that they are impressions made by escaping gases ascending through the muds; others, e.g., Kindle (1916, p. 542-547), are of the opinion that salinity of the water controls their formation due to vertical currents. Still others are proponents of Schofield and Keen's (1929, p. 492-493) belief that the muds are deposited under acidic conditions in which acid concentration controls the development of these structures by influencing thexotropic gel formation.

Secondary (Chemical) Features

Concretions

Concretions are a prevalent feature of the sedimentary structures in the Devonian-Mississippian shale sequence. The most conspicuous type is composed of carbonate. Mineralogically two types prevail: (1) calcite or Olentangy shale type and (2) dolomite or Ohio shale type. The next most conspicuous, though more abundant, is iron sulfide (pyrite or marcasite) concretions (nodules). Small collophane (phosphatic) nodules are found occasionally but not as frequently as in related shales in other regions.

Carbonate concretions in the Olentangy shale. - Carbonate concretions of variable form are found at a number of horizons in the Olentangy shale. They occur as isolated concretions or in lenticular masses, at some places joined to form continuous beds up to 10 inches in thickness. The isolated concretions occur more often at certain levels near the top of the shale. In these, some concretions are larger and more irregular, reaching 2 feet in diameter. The lenticular masses are more typical toward the bottom of the Olentangy shale.

The more common variety is from half a foot to 1 foot in diameter, circular in the horizontal plane, and nearly elliptical in vertical section (though more pointed below than above). They are the same blue-gray color as the enclosing shale. A shell of marcasite surrounds the concretion about half an inch from the outside. Texturally, they are fine grained to dense, and are broken with difficulty with a sledge, though on exposure they weath er rapidly into a heap of small angular fragments.

Westgate (1926, p. 53-54) has reported as follows concerning the chemical and petrographic analysis of the Olentangy carbonate concretions:

...A sample collected from one of these lower layers...was analyzed by Prof. J. D. 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
Sulfur, S	.305
Moisture at 105°C	.16
Total	99.495

This analysis recalculated for the mineral composition, and to a 100 percent 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, $Al_2O_3 \cdot 2SiO_2 - 2 H_2O$	8.35
Pyrite, FeS_2	.57
Total	100.

In thin section 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 slide 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 sulfide occur, many of them small cubes (pyrite), to .04 mm. A very little chalcedonic quartz shows. The sections are taken from different pieces than those used for the analysis, hence the variation from the calculated amount of pyrite and quartz.

The origin of these concretions has not been investigated. Perhaps their mode of origin is similar to that proposed by Clifton for the Ohio shale concretions.

<u>Carbonate concretions in the Ohio shale.</u> - The lower part of the Ohio shale, like the Cleveland shale, is characterized by calcareous sedimentary structures, which were called "iron-stone" by Stauffer (1911, p. 25-26), but are commonly referred to as carbonate concretions. Generally, carbonate concretions are regarded as confined to the Huron member. Nelson (1955, p. 25, 29, 57), Cushing and others (1931, p. 36-37), and other workers note the presence of discoidal carbonate concretions in the Cleveland shale (Vermilion facies) and clay-ironstone concretions containing the iron carbonate mineral, siderite, in the Chagrin shale. This discussion is concerned with concretions observed in the Huron portion of the shale.

Laterally, these concretions are found at definite horizons at any one outcrop locality (fig. 10-A). They range from 1 to 15 feet in diameter, but are generally 6 feet or less. The smaller ones are nearly spherical, whereas the larger ones are somewhat ellipsoidal. Many of the larger ones are concave on the top and bottom (fig. 10-B and C). The outer surfaces often have a protrusion around the middle. The bedding of the shale is bent above and below the concretions, and where a concretion is broken vertically it is seen that the shale laminae pass through the concretion curved in the same fashion as, but to a lesser degree than, the enclosing shale (fig. 10-D). The main body of the concretions consists of horizontal laminae as a series of light and dark bands, each band being from half an inch to several inches thick. Due to differential weathering, the light bands, which contain more chert than the dark bands, remain as ridges on the surface. The smaller concretions are solid to the center, but the centers of the larger ones frequently possess a septarian structure with the fissures filled with either secondary calcite or barite (fig. 10-E). The concretionary material is usually secondary crystals of calcite, dolomite, quartz, pyrite, and barite incorporated in a nonidentifiable fine-grained matrix of carbonate, silica, and organic matter. Plant and animal matter is common throughout the concretions. Fish bones, conodonts, fossil wood (Dadoxylon newberryi), and ostracods often serve as the nucleus about which the concretion grew. Nearly all the fossils are carbonate or silica replacements of the parent material.

Westgate (1926, p. 55-56) gives the following chemical and petrographic analysis of the concretions:

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
Sulfur, S	.675
Moisture at 105°	.20
Total	99.645

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

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

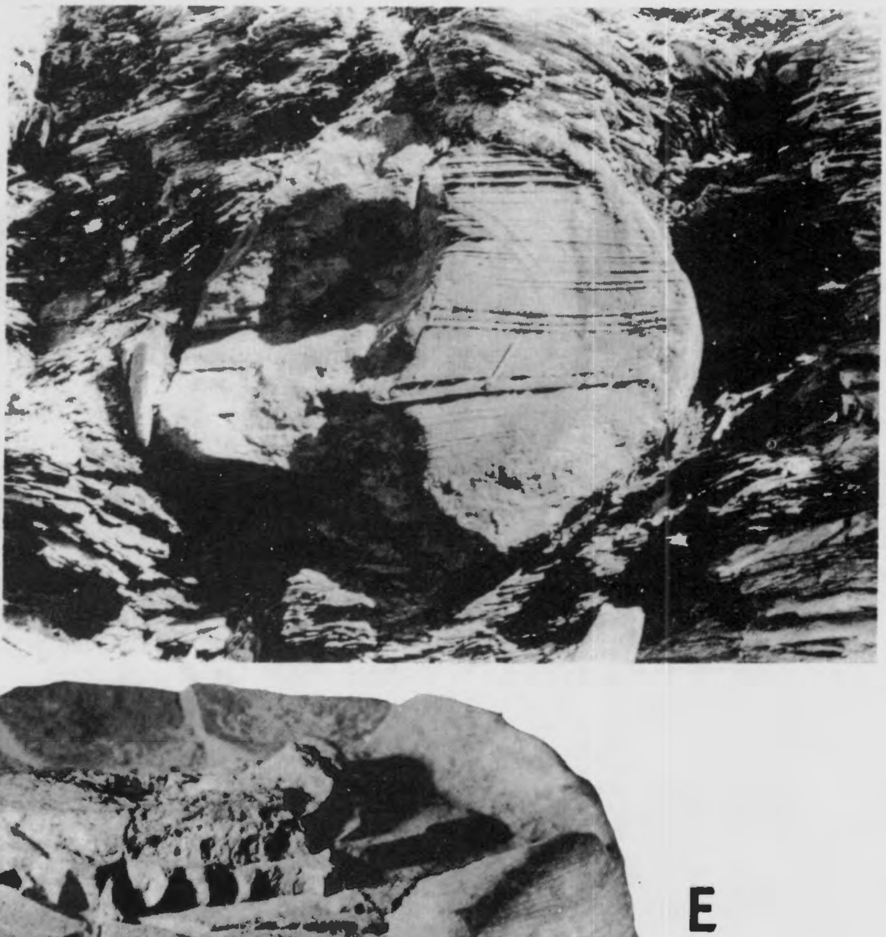
Figure 10. - Ohio shale carbonate concretions. (opposite page)

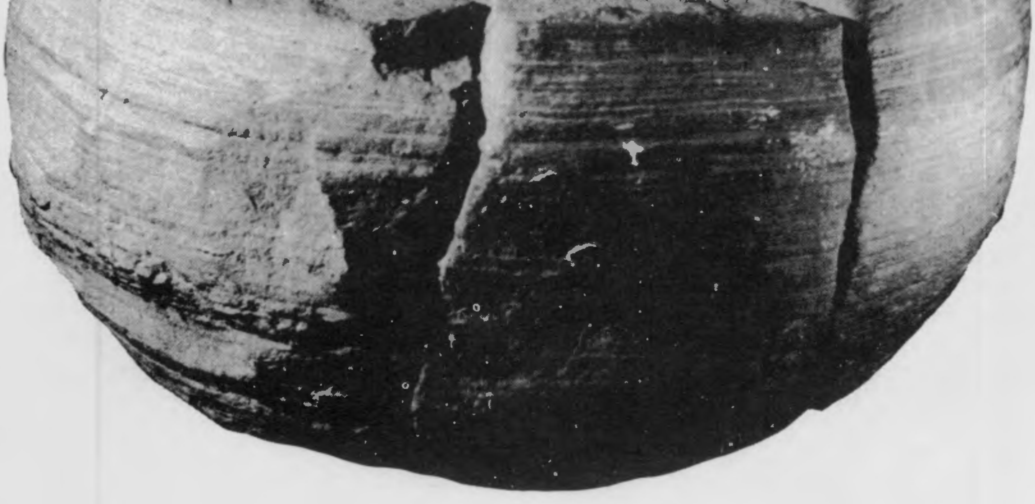
A. - Carbonate-concretion horizon of the lower Ohio shale, along an unnamed tributary to the Olentangy River, 1½ miles north of Worthington, Ohio.
B. - Concavity in the top of a typical Ohio shale carbonate concretion.
C. - Small Ohio shale carbonate concretion sitting inside the concavity of a medium-sized concretion.
D. - Ohio shale carbonate concretion, the Narrows, Olentangy River, Franklin County, Ohio, showing the fracturing, horizontal stratification, and draping of black shales above and below the concretion. Lead pencil in photo shows scale.
E. - Typical Ohio shale carbonate concretion showing carbonate core and alternating protuberance around center of the concretion.

B

C

D





E

The differences between the carbonate concretions in the Olentangy and the Ohio shales seem to be a matter of relative mineral percentages as well as physical form. Though the total percentages of carbonates are comparable, the Olentangy shale carbonates are high in calcite, whereas the dominant carbonate in the Ohio shale is dolomite. The Olentangy shale concretions are lenticular masses in the bottom portion and grade into spherical concretions (maximum diameter, 2 feet) toward the top. The Ohio shale concretions are either ellipsoidal or spherical, with a minimum average diameter about equal to the maximum of those in the Olentangy shale--that is, 2 feet.

The origin of these carbonate concretions in the Ohio shale has been the source of investigation by many workers studying the "Ohio Black Shale," and many theories concerning their origin have evolved. These theories center essentially around three modes of origin--namely, syngenetic (contemporaneous with enclosing rock), epigenetic (later than enclosing rock), and penecontemporaneous (almost contemporaneous with enclosing rock). The early investigators relied upon field observations in drawing their conclusions concerning the origin of these concretions. Two schools of thought prevailed: Newberry (1873, p. 155) and Orton (1878, p. 635-636) felt that the concretions were syngenetic, whereas Daly (1900, p. 143-144), who investigated the concretions of the "Black shales" in Canada, Stauffer and others (1911, p. 25-26), and Westgate (1926, p. 54-56) regarded these concretions as epigenetic.

The first research to utilize both field and laboratory relationships in developing a theory of the origin of these concretions is the work performed by H. E. Clifton, who developed the penecontemporaneous theory of origin for the carbonate concretions in the Ohio shale. Clifton (1957, p. 124) has summarized his findings as follows:

> The evidence suggests that the concretions formed after the deposition of the enclosing sediments but before complete compaction of the muds. Crystallization began around a nucleus and spread outward. . Replacement and secondary growth of crystals were important processes during the development of the concretion. Horizontal banding in the concretion is an expression of the compaction of the mud, frozen by crystallization. Additional compaction, as recorded by laminae bending toward the center plane, squeezed out the water and halted further growth. . . . Because water in the compacted mud would tend to circulate in horizontal planes, the larger concretions grow faster laterally, resulting in flattened ellipsoids. The smaller concretions were not affected by this, as the charged water could more easily reach all points on the surface. The arching of the shale above and below the concretion is due to the compaction and shrinkage of the mud around the solid object.

It is from these concretions that many sharks and the large fish, Titanichthys and Dinichthys, have been obtained, which have made Ohio shale world famous from a paleontological standpoint.

Pyrite nodules (iron sulfide concretions). - Iron sulfide crystallizes into two very common iron minerals, pyrite and marcasite. These minerals are generally distinguished by differences in crystal form, color, specific gravity, and manner in which they decompose under natural or artificial conditions. Most of these methods of distinguishing pyrite and marcasite are not very satisfactory, and not usually applicable to concretionary masses or to mixtures of the two minerals.

Generally, the iron sulfide concretions in the Devonian-Mississippian shales have been referred to indiscriminately as either pyrite or marcasite nodules. The mineralogical content of these concretions in the Ohio and Bedford shales in the Cleveland, Ohio, region was the subject of an X-ray analysis study performed by Van Horn and Van Horn (1933). The results of their crystallographic observations and X-ray analyses revealed that the iron sulfide in these shales was in the form of the mineral pyrite. However, they reported that marcasite was present in the iron sulfide nodules of the Olentangy shale in central Ohio.

The iron sulfide occurs in the form of balls, lenses, continuous layers, thin sheets, encrustations, and fossil replacements. Lenses and pyrite layers normally occur within the shale along the bedding planes. Sheets and encrustations of pyrite are found in the joint planes and faults. Nodules might be found in random orientation within the shale. Frequently the nodules are associated with the more silty phases or pyritized organic material.

There are three well-defined habits or types in which the iron sulfide concretions are found in the shale. These may be classified as follows: (1) cubes with curved or roughened faces which sometimes occur individually but more frequently as irregular aggregates; (2) parallel growths or groups which consist of aggregates of curved cubes elongated in the direction of the trigonal axis (normal to the face of the octahedron) (This type resembles the spearhead twins of marcasite); (3) (the most abundant), small or large nodules which are sometimes massively compact but which usually exhibit a fibrous radiated structure.

Cone-in-cone structures. - In the upper part of the Ohio shale, or Cleveland member, there are many thin calcareous layers displaying sedimentary structural features called cone-in-cone structures (fig. 11). Nelson (1955, p. 29) reports the presence of cone-in-cone structures near Berea in the top of the Chagrin shale. Because he reports them at the top of the Chagrin where he says the normal gray Chagrin shales are practically absent and blacker shales more like the Cleveland shale are found, we may assume that these beds have Cleveland affinity. The cone-in-cone structures are frequently in close proximity to silty plastic blue and gray clay-shale beds and are present as persistent layers or as lenticular bodies ranging from less than half an inch to more than 3 inches in thickness.

The cone-in-cone may be singular with apices generally pointing downward, double with one apex pointing upward and the other downward, or associated with carbonate concretions or disturbed material, in which case the apices may point in any direction. Many of the cones are iron stained, contorted or twisted, dense, and carbonaceous. These structures consist of a nest of concentric cones having heights of from a quarter inch to several inches, and basal diameters depending upon the height and angles of slope of the cones. The cones have apical angles which range from 30 to 60 degrees, with the larger ones commonly between 50 and 60 degrees (Karhi, 1948). The internal structure of the cone consists of fibers which are subcircular in cross section and which are either parallel or inclined to the axis of the cone. The main mineral constituents of cone-in-cone structures are carbonates and clay, and the remainder are mostly insoluble minerals. The carbonate mineral in cone-in-cone structures, according to Twenhofel (1932, p. 722), is generally calcite, varying in amount from 60 to 98 percent. Karhi (1948) found the carbonate to be calcite and the insoluble minerals in the Ohio shale cone-in-cone structures to be composed of sericite, quartz, secondary barite, and pyrite. The pyrite was present either as nodules, disseminated throughout, or in some cases with apices adjacent to a thin pyrite layer.

Many theories have been advanced concerning the origin of the cone-in-cone structures. In essence, the theories suggest that they developed either by concretionary growth or by dynamic stresses. Louis Karhi (1948) attempted in a research study to clarify the various concepts of the occurrence of the cone-in-cone structures in the Ohio shale and to point toward a mode of origin. Karhi (1948, p. 49) concluded that these structures are of epigenetic origin and formed by effects of pressure and solution upon diagenetically developed calcareous layers.

Rock Joints and Fracture Systems

At nearly every exposure in the outcrop areas of the Devonian-Mississippian shales, the rocks are cut by joints. The joints trend in various directions, some closely and others widely spaced. Except for many weak fractures in all directions, which may be locally strong, the joints fall into two major sets (usually with nearly vertical dips).

Some joint surfaces are straight and smooth, others are "wavy," and there are all intermediate gradations. Some are poorly developed or jagged and irregular. Many of the joints are open fissures, some are narrow cracks, and a few are filled with weathered secondary iron debris or vein calcite.

Single joints normally extend across the entire length of any exposure, although some close and come to an end. Most joints have a great vertical as well as a great lateral extent. Individual joints can be traced from the tops to the bottoms of many exposures of these rocks. Where several sets of joints are present, they commonly cross one another without deflection, although in places subordinate sets either may end against or branch from the dominant sets. The observations made on the intersections of the joint sets are not sufficient to show whether some are of different ages than others. Such differences might be revealed by closer scrutiny. The spacing of the joints is variable for all stratigraphic divisions. To a large extent it seems to depend on the local tectonic relations, for the spacing in one area may tend to be more uniform in all divisions than that in another area. The systematic joints in most places stand nearly vertical. The greatest variation in dip is that detected in measuring the dip of an individual joint plane in vertical section.

Joint systems are conspicuous throughout the Ohio shale. Two master sets of joints, nearly at right angles to each other, appear to be the most important and are found to be present throughout the State. Stauffer and others (1911, p. 25) found this major system to be approximately northeast and northwest in direction for the Columbus region. Moses (1922, p. 62) studied the joint systems of the Ohio shale in the Bellefontaine outlier area. Moses reported the directions of the major sets to be N. 40° W. and N. 55° E. In northeastern Ohio, Hutton (1940, p. 14, fig. 4) investigated the distribution of the Ohio shale joints for the Conneaut and Ashtabula quadrangles. The master sets trend N. 40° E. and N. 55° W. in these quadrangles. Hutton's work reveals that the relative distribution of the northwest set shows much more variation than the northeast set. Joints having regional development do not show any distinctive characteristics by which they can be identified in the field independent of their positions. Many of the joint surfaces having regional development are curved and irregular, with a rough, torn appearance. Both major and minor sets slice cleanly through the Huron shale carbonate concretions. They pass without deviation through the limestone beds containing cone-in-cone structures and zones of contemporaneous deformation as well as through structures developed before the sediments were indurated.

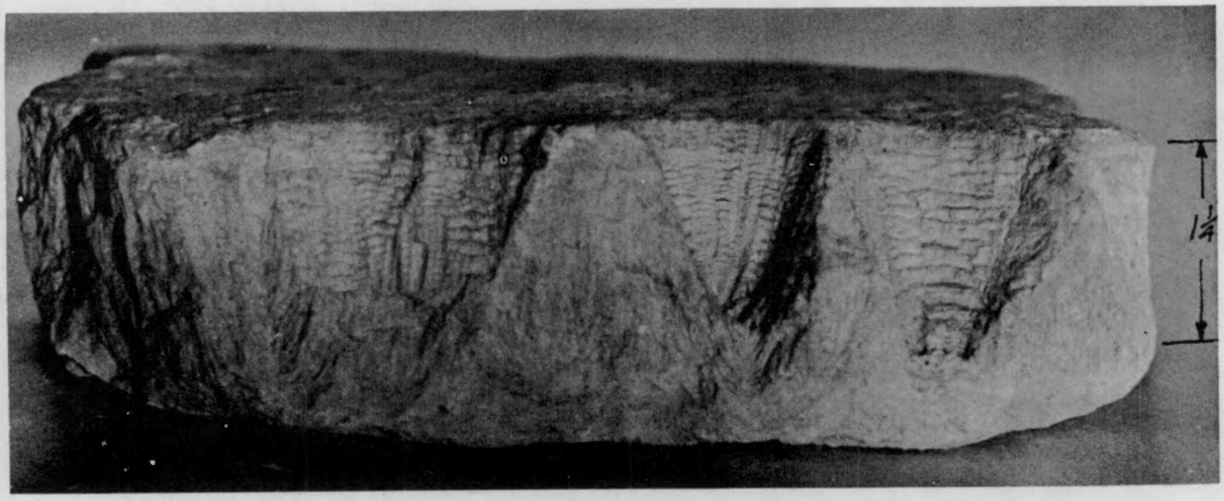


Figure 11. - Cone-in-cone structures from the Ohio shale, Logan County, Ohio.

In addition to the joint sets, the Devonian-Mississippian shale sequence possesses "hackly" fractures, which are so irregular that no dip or strike can be measured on them. They are present wherever these shales crop out. The density varies from outcrop to outcrop, but no statistical work is possible since they possess no orientation that can be plotted.

So little areal work has been performed on the jointing in these shales that the literature does not contain any interpretation of origin of these joints. Westgate (1926, p. 57) says that the vast majority are the result of bending and twisting of the beds after partial or complete solidification. Hutton (1940, p. 15-16) believes that the joints in the Ohio shale are post-Devonian in age and that they are the result of great forces exerting pressure along the earth's surface.

Unconformities

Recognizable unconformities exist at the base and top of the Devonian-Mississippian shale sequence. Some investigators have proposed that there are also unconformities within the series, but it is difficult to demonstrate their presence, and there is a difference of opinion on the subject.

On the outcrop, the Olentangy shale rests on limestone ranging from Silurian to Middle Devonian in age. This unconformity is demonstrable on both physical and faunal grounds. However, the physical evidence is hard to present because of lack of outcrops and because the unconformity occurs in a region of horizontal or but slightly dipping rock, where there is no discordance of the strata to make it easily detectable. Lamborn (1927; 1929) has reported areas in southern Ohio in which the Olentangy shale is missing. It is upon his work that our present knowledge of the physical evidence of an unconformity between the Ohio shale portion of the shale sequence and the underlying limestones is based. Faunally, it has been demonstrated by the paleostratigraphers that the shale series rests upon limestones of various ages in different regions. The relationship of the Prout limestone and Plum Brook shale to the Olentangy shale has resulted in the belief that there is an unconformity between the Huron shale and Prout limestone (Stauffer, 1916, p. 485-487) in north-central Ohio. Though no physical evidence is available, the fauna suggests that the Prout limestone is separated from the overlying Huron shale by a nondeposition hiatus of long duration.

The relationships among the three Ohio shale units in the Cleveland area have been variously interpreted, including the possibility of an unconformity existing between the Cleveland and Chagrin shales. Cushing (1912), and Cushing and others (1931, p. 38-40), and Chadwick (1925, p. 461) have placed a disconformity between these two Ohio shale units. They are of the opinion that the Chagrin was subject to considerable erosion prior to Cleveland deposition, giving as physical evidence for the existence of an unconformity the presence of a weathered clayey material and a highly charged marcasite bed at the contact, plus slight irregularities in the surface of the uppermost bed of the Chagrin shale. Chadwick (1925, p. 461) has reported that at one place the uppermost Chagrin beneath the summit unconformity is the Millers sandstone, "characterized by its abundant fauna," and at another it is the Woodcock, similarly characterized. Nelson (1955, p. 23) recognizes possible disconformities at the top and bottom contacts of the Cleveland shale Trumbull facies. He believes that the upper contact of the Cleveland shale Vermilion facies with the overlying Bedford shale may be either slightly diastemic or gradational.

Many papers have been written concerning the unconformity that exists at the Bedford shale-Berea sandstone contact. Northward from Fairfield County to the shores of Lake Erie the physical evidence for this unconformity is abundant. Many outcrop sections attest to the fact that channels now filled with Berea sandstone were developed during the period when the Bedford horizon was above the base level of deposition and its surface was dissected by streams. The lower portions of these stream valleys became drowned, and blue shale sediments were deposited with typical Berea sediments inundating the region as the Bedford land area gradually submerged. Southward from Fairfield County the Bedford and Berea sediments are hard to distinguish, with the result that no unconformity is thought to exist.

Structural and Isopachous Maps

The regional structure of the eastern half of Ohio as depicted by the shale sequence is outlined by a structure-contour map (pl. 2) drawn on the top of the Bedford shale. An isopachous map (pl. 3), and a fence diagram (pl. 1), amplify the structural map. The regional structural features are: (1) an axis extending northeast-southwest and lying west of the present limit of the shale sequence (axis of the Findlay arch), (2) a channel or trough extending southeastward from Lorain County on Lake Erie (well developed southward from Coshocton County) across Ohio to the Ohio River in the vicinity of Marietta (axis of the Parkersburg-Lorain syncline), and (3) upwarping of the northeast portion of the State with dips extending toward the south (influence of the Canadian shield). The shape and position of the regional features mapped on the top of the Bedford shale (Early Mississippian) are generally the same as those shown on structure-contour maps that have utilized data for both older and younger formations (see Pirtle, 1932; Lafferty, 1941; Pepper, 1954; Lamborn, Ohio Div. Geol. Survey open files). Variations of these structural maps seem to be controlled by the eastward or westward shifting of the Appalachian geosynclinal axis throughout the long span of geologic time during which this depositional basin was receiving sediments.

The northern continuation of the Findlay arch is broken by a downwarp in Ontario known as the Ontario sag. It is not known whether this sag was sufficiently great during the deposition of the Devonian-Mississippian shale sequence to connect the Michigan and Ohio basins. Subsequent erosion has removed all of the rocks on the arch in northern Ohio down to those of Lower Ordovician age. Lockett (1947, p. 433) estimates that this part of the arch has subsided 2,000 feet since Trenton (Ordovician) time, so possibly the arch was downwarped enough during at least part of the time of shale deposition to have sediments passing over the sag. Until information from more borehole studies becomes available, further speculation on structural conditions of the sag does not appear appropriate.

The most important factor to be considered in interpolating the structure of beds lying below the Berea sandstone is the rapid thickening of the rock belonging to the Devonian and Silurian systems. This thickening is given by Stout (1918, p. 287-288) as 35 feet to the mile to the east, and 0.74 foot to the mile to the south. Lockett (1927, p. 1026) has reported that in Harrison and Columbiana Counties, which lie east of the area reported on by Stout, the rate of thickening increases to at least 50 feet to the mile.

Study of the isopachous map shows that sufficient data were not available to contour the outcrop area of the shale sequence. Lamborn (1934, p. 355) has reported an irregular thickening of the shale series along the outcrop, from about 340 feet in eastern Adams County to about 550 feet in Erie County. This amounts to an approximate thickening of 1.2 feet per mile along the strike of the outcrop. In the subsurface the shale series eastward from the area of outcrop shows a much greater rate of increase in thickness. The rate of eastern thickening is greater in southern than in northern Ohio. The shale exceeds 3,700 feet in thickness within the boundaries of the State; in section 18, St. Clair Township, Columbiana County, the drill has penetrated 3,735 feet of Devonian-Mississippian shales. Table 1 gives the increase in shale thickness between various geographic localities in Ohio.

A study of the isopachous map and table 1 shows that an abrupt increase of thickness occurs east of a line that generally follows the 1900 foot isopachous line. The 1900 foot isopach roughly parallels the "hinge line" between the epicontinental shelf of Lafferty (1941) and the geosyncline proper. East of the 1900 foot isopach, then, the geosyncline apparently was sinking faster under the weight of sediment load.

Table 1
INCREASE IN THICKNESS OF THE DEVONIAN-MISSISSIPPIAN SHALE SEQUENCE BETWEEN GIVEN GEOGRAPHIC POINTS

From	To	Thickness (ft.) From	Thickness (ft.) To	Approx. mileage	Rate of increase (ft./mi.)
Lorain, Ohio	Andover, Ohio	800	2000	85.5	14.0
"	Farmdale	800	2650	82.5	22.5
Oberlin	Windham	800	2150	62.5	21.6
"	Warren	800	2550	75.0	23.3
"	Sharon	800	2800	89.5	22.3
Windham	Sharon	2150	2800	28.0	23.9
Medina	Youngstown	1250	2900	64.0	25.8
"	Struthers	1250	3050	67.0	26.8
Ashland	East Liverpool	900	3700	94.5	29.7
Mansfield	Canton	750	2100	60.0	22.5
Mansfield	Negley	750	3500	105.5	26.0
Canton	Negley	2100	3500	45.5	30.7
Mt. Vernon	Coshocton	800	1600	35.0	22.7
"	Steubenville	800	3550	100.0	27.5
Coshocton	Steubenville	1600	3550	66.0	29.5
Newark	Martins Ferry	1000	3700	91.0	23.7
Lancaster	McConnelsville	850	1800	39.0	24.0
"	Duffy	850	3650	91.0	30.1
McConnelsville	Duffy	1800	3650	53.0	35.0
Logan	Marietta	1050	2650	53.0	30.3
Logan	Richie Co., W. Va.	1050	3600[a]	78.0	32.6
"	" "	1050	3800[a]	78.0	35.3
Marietta	" "	2650	3600[a]	25.0	38.0
"	" "	2650	3800[a]	25.0	46.0
Waverly	Pomeroy	550	1750	53.0	22.7
Waverly	Roane Co., W. Va.	550	3600[a]	102.0	29.6
"	" "	550	3370	102.0	27.3
Pomeroy	" "	1750	3600[a]	49.0	37.7
"	" "	1750	3370[a]	49.0	33.1
Portsmouth	Gallipolis	600	1450	42.0	20.4
Portsmouth	Roane Co., W. Va.	600	3600[a]	100.0	30.0
"	" "	600	3370[a]	100.0	27.7
Gallipolis	" "	1450	3600[a]	58.0	35.95
"	" "	1450	3370[a]	58.0	34.6

a - Estimated

Chapter 3

ECONOMIC GEOLOGY

URANIUM

Though the Ohio shale is known to contain uranium, and thorium has been reported to be present, the quantity is too small to have inaugurated any uranium research. These uranium-bearing rocks are black shales similar to those from which uranium is recovered in Sweden. Most chemical assays of the more radioactive portions of the formation (usually the black beds) show about 0.003 percent uranium. It is suspected that the highest readings are limited to outcrop and joint faces where the uranium has been secondarily concentrated by weathering processes. The thorium in the Ohio shale is considered to be confined to the gray layers. In the light of our present knowledge it is believed that the uranium content of the Ohio shale is far too lean for commercial development. If some method could be found to profitably convert the bitumin in the shale to oil, and to utilize the clay minerals, the uranium might be recovered as a byproduct. The U. S. Atomic Energy Commission makes bonus payments on uranium ore assaying 0.1 percent (or better) U_3O_8 produced from eligible mining property. This 0.1 percent minimum is about 30 times the known concentration of uranium in the Ohio shale.

OIL SHALE

It has long been known that many black shales contain appreciable amounts of bituminous or carbonaceous matter and that most such shales, if heated, will yield gas, oil, and other byproducts. Many people have realized that the time would come in this country when the decline in yield of domestic and foreign oil fields would lead to testing the black shales as a possible source of oil. The annual increase in use of petroleum fuels and the uncertainty of foreign supplies, resulting from international unrest which threatens safe passage of ocean-going oil tankers, has renewed interest in the black shales.

The Ohio shale is the principal oil-bearing shale in Ohio. Oil also occurs in the Olentangy and Sunbury shales, and in shales associated with coal. The Ohio shale has been the object of several oil-shale investigations. Ashley (1917, p. 314-315, 319) analyzed two samples of the Ohio shale from Glen Mary Ravine, 8 miles north of Columbus, Ohio. He reported yields per short ton as follows:

Oil (gals.)	5.6 to 9.0
Gas (cu. ft.)	958 to 1,119
Ammonia (lbs.)	0.0 to 0.11

Miller (1944) performed tests on Ohio shale samples collected from several localities within the State. The object of Miller's assays was not so much to determine quantitative reserves of oil as to develop the best extraction method to obtain optimum yield. He discovered that varying such factors as rate of retorting and sizing of the raw shale affected volume yield and quality of the product. The yields of his samples are given in table 2.

Miller combined the total accumulation of oil obtained from his assays to make a fractional distillation and a viscosity test. He believed that his results were probably representative of what might be expected from a commercial shale-oil plant. They are as follows (After Miller, 1944, table 6):

Oil charged (cc)	Viscosity crude-SUS	API crude 60° F	Motor oil (cc)	Motor fuel (percent)
100	44.4	25.1	43.5	43.5

Miller (1944, p. 20-22) concluded from his investigations that the Ohio shale could not support a shale-oil industry at that time, since the financial returns on the oil obtained from the shale would be only a fraction of the cost of mining the shale.

The Ohio State University Engineering Experiment Station in cooperation with the Ohio Division of Geological Survey has been performing a series of assays of the Ohio shale. Results of this research have been made available in the various publications of the Experiment Station (Kerr, 1948; Krumin, 1949, 1951). The efforts of the Experiment Station were particularily concentrated on a test core, called the Chillicothe test core (Carman, 1947), and a nearly complete section from the outcrop at Copperas Mountain, both in Ross County, Ohio. Table 3 contains a tabulation of the assay data on both the Chillicothe core hole and the Copperas Mountain section and indicates a general correlation between these two localities.

A comparison of data on the Chillicothe core hole and the Copperas Mountain outcrop indicates that the 376 feet of section assayed from the Chillicothe core hole yielded 0.25 to 14 gallons of oil per ton and averaged 5.5 gallons per ton, whereas the 251-foot section assayed from Copperas Mountain produced 1.5 to 8.2 gallons per ton and averaged 3.5 gallons per ton. Although the average yield of all samples from Copperas Mountain is generally lower than that obtained from the Chillicothe core hole, the table of assay data and other data indicate that a rather close correlation exists between the two localities. The richest shales in each locality occur in the upper 20 feet of the Ohio shale section. Another rich zone occurs in the interval between 280 and 300 feet below the top of the formation. In a more general sense, the upper 80 feet at both localities contains the richest shales. The next underlying 80-foot zone, 80 to 160 feet below the top of the formation, contains the leanest shales, and the next 140-foot zone, 160 to 300 feet below the top of the section, contains middle-grade shale which shows a general increase in richness toward the base. On the basis of this correlation the lower 76 feet of Ohio shale at the Chillicothe core hole does not appear to be present at Copperas Mountain.

The Chillicothe core hole penetrated 64 feet of Olentangy shale. Two samples of core, one taken 18 feet below the top of the Olentangy and the other at the base of the formation, assayed only 1.35 and 5.5 gallons per ton, respectively (Kerr, 1948). No additional data are available concerning the Olentangy shale at other localities, and the Devonian-Mississippian shales at this locality are of insufficient richness and thickness to meet the minimum requirements of an oil-shale deposit.

Table 2. -
YIELDS OF SYNTHETIC LIQUID FUEL FROM THE OHIO SHALE
(After Miller, 1944, tables 1, 2, 3, 4, and 5)

Sample	Location	Weight of charge (g)	Water (cc)	Total distillate (cc)	Oil (gals. /ton)	Specific gravity (degrees API at 60° F.)
1	North Columbus	400	-	9.0	5.39	-
3	"	400	-	9.0	5.39	-
4	"	416	-	9.5	5.46	-
5	"	400	-	9.0	5.39	-
6	"	420	-	9.0	5.14	-
7	Copperas Mtn.	400	-	14.0	8.3	-
8	"	400	-	15.0	8.99	-
9	"	400	-	15.0	-	-
10	"	400	-	15.0	-	-
11	"	400	-	15.0	-	-
12	"	400	-	15.0	-	-
13	"	400	-	15.0	-	-
14	"	400	-	13.0	-	-
15	"	400	-	17.0	-	-
16	"	400	-	14.0	-	-
17	Barberton, O. core	439	-	9.75	5.32	-
18	"	451	-	10.0	5.31	-
19	"	463	-	11.0	6.4	-
20	Copperas Mtn.	479.32	7.5	26.0	9.25	25.0
21	"	479.32	11.0	29.5	9.25	24.6
22	"	479.32	7.5	25.7	9.1	24.5
23	"	479.32	12.0	30.0	9.0	24.5
24	"	479.32	7.0	25.0	9.0	25.8
25	"	479.32	9.5	28.2	9.32	25.8

Table 3. -
COMPARISON OF ASSAY DATA ON THE OHIO SHALE FROM THE CHILLICOTHE CORE HOLE AND COPPERAS MOUNTAIN OUTCROP AREA

Chillicothe core hole			Copperas Mountain outcrop section		
Depth from top of Ohio shale (feet)	Thickness sampled (feet)	Average oil yield [a] (gals. /ton)	Depth from top of Ohio shale (feet)	Thickness sampled (feet)	Average oil yield [b] (gals. /ton)
0-20	20	10.48	0-19	19	6.2
20-40	20	7.58	19-39	20	5.4
40-60	20	6.52	39-59	20	4.9
60-80	20	5.64	59-75	16	2.7
80-100	20	3.13	75-97	22	1.7
100-120	20	2.49	97-108	11	1.6
120-140	20	2.61	108-157	(49 not sampled)	
140-160	20	2.56	157-177	20	1.8
160-180	20	3.47	177-197	20	2.8
180-200	20	5.04	197-217	20	3.0
200-220	20	5.23	217-237	20	3.0
220-240	20	5.03	237-257	20	3.5
240-260	20	4.56	257-277	20	3.7
260-280	20	6.05	277-300	23	4.9
280-300	20	8.02			
300-320	20	6.63			
320-340	20	6.34			
340-360	20	6.98			
360-376	16	7.18			
0-376	376	5.5	0-300	251	3.5

a - Bureau of Mines assay method.
b - Modified Fischer assay method.

Other Ohio shale oil assays, described by county, are as follows:

Highland and Adams Counties: Random samples and channel samples have yielded results varying from 3. 2 to 7. 2 gallons per ton.

Pike County: Fenneman (1927) reports that Bucher, in describing early work on the oil shales from Pike County, indicates that there are no beds which could yield more than 12. 5 gallons per ton, and that the average obtained was about 6 gallons per ton.

Scioto County: On the Ohio River near Buena Vista, Ohio, a plant producing 300 gallons per day of light oil from the Ohio shale is said to have been operating in the 1850's (Stout and others, 1943, p. 131). The oil shale, which is reported to be about 250 to 320 feet thick in this area, was mined from open cuts on the side of a hill, near the top of the formation. Recent sampling of a 6-foot section lying 15 feet below the top of the oil shale measured in one of the old excavations ran only 7. 4 gallons per ton.

Franklin County: In the general area of Columbus, Ohio, Kerr (1948) has reported a general yield of 5. 2 gallons per ton. Ashley (1917) reported upon two channel samples, near Glenmary Park and Flint Run, covering an interval of 8 feet from the lower portion of the Ohio shale. These samples yielded 5. 6 and 7. 7 gallons per ton. A random sample obtained from the same area is reported by Kerr (1948) as yielding 8. 2 gallons per ton. Approximately 130 feet of the basal portion of the Ohio shale is present in this general area. Well records indicate that the Ohio shale is between 600 and 650 feet thick (Bownocker and others, 1914; 1915).

Delaware County: Kerr (1948) reports that a series of random samples collected in Delaware County yielded 9. 6 gallons per ton.

Logan County: A composite sample from near Slaty Hollow representing 75 feet of section was obtained for oil analysis by taking a chip of the formation every 6 inches. This sample yielded 5. 5 gallons per ton.

Erie County: A sample taken from a 14-foot exposure of the Huron member of the Ohio shale from near Milan yielded 5. 2 gallons of oil per ton.

Deposits of oil shale are not considered to be a reserve of raw material for synthetic liquid fuels manufacture unless they (1) have an average oil content of at least 15 gallons per ton of oil shale, (2) have a minimum thickness of 25 feet, and (3) total not less than 100 million tons of oil shale within an area not greater than 5 square miles. For fuel manufacture 25 gallons per ton is the minimum presently considered, but a limit of 15 gallons per ton is set to include deposits of possible future importance.

A review of all available data indicates that the Ohio and Olentangy shales are not of sufficient richness to be a source of raw material for synthetic liquid fuel manufacture, nor do these data indicate that additional sampling and assaying are likely to reveal the presence of shales of sufficient richness to meet the minimum requirements for a reserve, as presently defined. The inorganic material (residue) in oil shale after distillation is composed mainly of complex silicates containing aluminum, iron, and calcium. This inorganic material, much of which is structureless, forms by far the largest proportion of the shale. Research may determine that this residue can be utilized in cement making or in manufacture of light-weight aggregate. Gold, silver, platinum and rare earths have been reported as occurring in some oil shales, but an investigation made by the U. S. Bureau of Mines (Gravin, 1922) indicated that oil shales would never be a commercial source of these or allied precious metals. The Ohio shale contains some phosphates and a small quantity of potash, but the amount is insufficient to make their recovery commercially profitable.

OIL AND GAS

Locally, wells in the Devonian shales are small producers of oil, usually no more than 10 or 15 barrels a day, and even such yields have been limited to a very few days at most. As is true for oil, the lack of sandstone reservoirs inhibits large gas accumulations, but many wells produce enough for domestic use. The stock of gas derived from these shales, though only moderate in amount, is quite persistent, and therfore valuable. It is low-pressure gas, rarely being known to rise beyond 100 pounds per square inch pressure, but its composition is considered to be very good. Rarely does a shale well produce more than 100,000 cubic feet per day; 50,000 cubic feet per day is regarded as excellent production. No gas supply is known that is more enduring than the supply derived from these shales.

The source of the gas secured from these shales is not at any one horizon, but varies stratigraphically from place to place. Because of the uniform fineness of the shales and absence of sandstone reservoir bodies, it seems probable that slight disturbances, which would be inadequate to secure gas concentrations in the great gas-bearing rocks, are much more effective in the Ohio shale. Thus it appears that it may be essential to have a finely divided network of rock fractures and joint systems to produce a local pool of gas in the Ohio shale.

The principal gas-producing counties in Ohio have been those along Lake Erie, particularily those in the northeastern corner of the State. Here there are many shallow wells drilled in shale to depths of 300 to 600 feet. In this area the best wells gauge from 25,000 to 50,000 cubic feet of gas per day, with a rock pressure of 40 to 60 pounds per square inch. Many of these wells have furnished local household fuel since the 1870's. The gas appears to be confined to openings along the joint planes. Also, the Ohio shale has yielded scattered wells of small magnitude in central Ohio and gives promise of fair returns in a field north of Portsmouth and east of Waverly, Ohio. It has been commercially productive in a few wells in southern Lawrence County.

CERAMIC PRODUCTS

The ceramic properties of the Devonian-Mississippian shale sequence have been considered in two publications dealing with surface clays and shales of Ohio. A preliminary report by Chester R. Austin on the physical tests and properties of the samples was published in 1934 as Bulletin 81 of the Ohio State University Engineering Experiment Station. A final report, published as Geological Survey of Ohio Bulletin 39 (Lamborn and others, 1938) gives a brief account of the general geology of the various deposits, and the chemical analyses and results of physical tests of samples representing various shale units.

These shales do not have the ceramic properties necessary for use in the pottery or refractory industry. The Bedford and locally the Olentangy shales, however, are suitable for making flue liners, paving brick, common brick, face brick, and drain tile. These shales have been extensively used for such purposes by various clayware companies located along the outcrop belt. However, with technological advances and better transportation facilities, these shales have not been able to compete economically in some geographic areas with products manufactured from clays of Pennsylvanian age.

The following is a summary of the chemical and physical properties of these shales as reported by Lamborn and others (1938, p. 29-50) from various geographic localities along the outcrop where they have been exploited for ceramic uses:

The Olentangy shale was formerly worked to some extent by the National Fireproofing Company at Delaware, where it was mixed with the overlying Ohio shale and used for the manufacture of brick and hollow tile. A sample of the shale at this place shows the following composition.

Chemical analysis

Loss at 105°C	1.21
Ignition loss	8.02
Silica, SiO_2	57.22
Alumina, Al_2O_3	16.15
Titanic oxide, TiO_2	1.26
Phosphorus pentoxide, P_2O_5	0.099
Ferric oxide, Fe_2O_3	4.78
Lime, CaO	3.71
Magnesia, MgO	2.31
Sodium oxide, Na_2O	0.16
Potassium oxide, K_2O	3.86
Manganous oxide	0.016
Sulfur, S	0.96
Total carbon, C	1.69
Inorganic carbon, C	1.00

Percentage oxide ratio

K_2O	.239				
Na_2O	.010				
CaO	.229			SiO_2	3.530
MgO	.143	Al_2O_3	1.00	TiO_2	.078
FeO	.266			P_2O_5	.006
MnO	.001				
RO	.888				

A microscopic examination of this shale was made by W. J. McCaughey who reported as follows:

"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 percent 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.

"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... [as also is] 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."

...As a source for ceramic products such as brick and tile, the Olentangy shale ranks low. Visible impurities such as lime nodules and pyrite concretions are plentiful and harmful ingredients. Furthermore, the presence of interstratified black shale, which cannot be separated economically in the working of the deposit, increases the carbon content and leads to difficulties in firing.

The Olentangy shale is not utilized at any place in Ohio for the manufacture of ceramic products.

...The Ohio shale has never been utilized for the manufacture of ceramic products in Ohio south of Franklin County. At Columbus the black shale of this formation mixed with a small percentage of glacial drift was formerly used for the manufacture of sewer pipe by the Columbus Sewer Pipe Company with fair results.

An analysis of an average sample of the shale used at this plant is given below. William McPherson, analyst.

Chemical analysis

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	0.44
Magnesia MgO	1.57
Potash K_2O	4.68
Soda Na_2O	0.34
	99.61
Fluxing impurities	12.81
Clay and sandy impurities	86.80

Up until 1928 the Shale Brick Company of Columbus worked a blue shale bed of the Ohio formation for the manufacture of common brick. Due to a shortage of available shale, the practice was changed and glacial drift is now being utilized. The black Ohio shale was also formerly used in a small way by the National Fireproofing Company at Delaware where it was mixed with the Olentangy shale and manufactured into hollow tile.

...In northern Ohio, which includes the outcrops from Erie County east to Pennsylvania State line, the Ohio shale formation has been divided into three parts as follows: Cleveland shale, Chagrin shale, Huron shale....

The Cleveland and Huron shales have received little attention in northern Ohio as sources of material for ceramic products, but the Chagrin shale has been utilized at a number of places at Cleveland and along the Lake front as far as Conneaut.

...At the plant of the Cleveland Brick and Clay Company, the Chagrin shale is used extensively for the manufacture of paving brick....

The Chagrin shale is used exclusively in this plant. A sample of the Chagrin exposed in the pit was cut on August 14, 1929, and was submitted for testing. The results are....

Sample No. 47
Tests of Chagrin shale from pit of Cleveland Brick & Clay Co., Cleveland, Cuyahoga County

Downs Shaaf, analyst

Chemical analysis

Water, hydroscopic, H_2O-	1.50
Water, combined, H_2O+	5.11
Silica, SiO_2	59.56
Alumina, Al_2O_3	15.90
Titanic oxide, TiO_2	1.05
Phosphorus pentoxide, P_2O_5	.18
Ferric oxide, Fe_2O_3	5.72
Ferrous oxide, FeO	4.06
Lime, CaO	.62
Magnesia, MgO	.36
Sodium oxide, Na_2O	.42
Potassium oxide, K_2O	3.50
Manganese oxide, MnO	.04
Ferrous sulfide, FeS	.88
Carbon dioxide, CO_2	1.02
Carbon, organic, C	.27

Oxide ratio

K_2O	.220				
Na_2O	.026				
CaO	.039				
MgO	.023			SiO_2	3.746
FeO	.613	Al_2O_3	1.00	TiO_2	.066
Mno	.002			P_2O_5	.011
RO	.923				

Physical properties, determined by Chester R. Austin
Properties in green state

Workability: This material has rather short plasticity. A badly featheredged column is extruded from the die.
Time of slaking: 58.40 minutes
Water of plasticity: 17.77 per cent
Dry shrinkage
Volume: 10.03 per cent
Linear: 3.24 per cent
Drying behavior: This material dries satisfactorily with ordinary care.
Dry modulus of rupture: 304 pounds per square inch.

Firing behavior

Cone	Apparent porosity (per cent)	Volume shrinkage (per cent)	Calculated linear shrinkage (per cent)
012	27.44	0.41+	0.47+
010	25.90	0.66	0.22
08	21.33	7.35	2.4
06	13.31	13.62	4.3
04	6.85	17.30	5.5
02	5.23	17.69	4.8
1	3.61	18.09	5.7

Cone	Absorption (per cent)	Bulk specific gravity	Apparent specific gravity
012	14.60	1.88	2.59
010	13.40	1.93	2.59
08	10.40	2.05	2.60
06	6.08	2.19	2.52
04	6.98	2.29	2.45
02	2.27	2.30	2.42
1	1.55	2.30	2.41

Fired modulus of rupture:
Cone 08, 2,036 pounds per square inch.
Cone 04, 3,526 pounds per square inch.
Fired specific impact strength:
Cone 05, 1.41 centimeter kilograms per square centimeter.
Cone 09, 1.17 centimeter kilograms per square centimeter.
Fired crushing strength:
Cone 04, 12,626 pounds per square inch.
Best firing range: Cone 010 to cone 02.
Overfiring temperature: Cone 1.
Pyrometric cone equivalent: Cone 11-12.
Scumming: Scumming takes place throughout the entire firing range of this material. Six pounds of $BaCO_3$ per ton of material is necessary to prevent scumming.
Salt glazing: This material does not withstand the temperature necessary for the formation of a good salt glaze.
Utilization: This shale was being used for the production of paving brick. Other possibilities for utilization consist of face brick and common brick. The fired material has a somewhat stony structure. A good red color is developed at cone 02.

Bedford shale has been utilized for a number of years for the production of face brick by the Claycraft Mining and Brick Company at Taylor, Jefferson Township, Franklin County. The shale, which is of the reddish-brown variety, has a thickness exposed in the pit of 25 to 40 feet, all of which is remarkably uniform in texture and appearance. A. E. MacGee of the National Bureau of Standards sampled the shales in this pit for testing.

Sample No. 202

Tests of Bedford shale from the pit of the Claycraft Mining & Brick Company, Taylor, Franklin County. (Tests by the National Bureau of Standards.)

Chemical analysis

Loss on ignition	7.0
Silica, SiO_2	59.4
Alumina, Al_2O_3	17.2
Ferric oxide, Fe_2O_3	8.9
Lime, CaO	0.5
Magnesia, MgO	1.5
Titanic oxide, TiO_2	1.2
Sodium oxide, Na_2O	0.2
Potassium oxide, K_2O	2.9
Sulfur, S	0.0
Total Carbon, C	0.6

Oxide ratio

K_2O	.17				
Na_2O	.01				
CaO	.03			SiO_2	3.45
MgO	.09	Al_2O_3	1.00		
FeO	.46			TiO_2	0.07
RO	.76				

Physical tests

Tempering water: About 20 per cent.
Drying linear shrinkage: About 5 to 6 per cent.
Drying volume shrinkage: About 17 to 18 per cent.

Burning behavior

Burning temperature	Linear shrinkage (per cent)	Volume shrinkage (per cent)	Volume absorption (per cent)	Color
Cone 08	1.3	3.9	11.4	Buff
Cone 06	4.1	11.8	7.9	Salmon
Cone 04	5.8	16.5	5.0	Tan
Cone 03	6.6	18.4	3.2	Gray
Cone 02	7.1	19.8	1.7	Brown
Cone 01	6.9	19.3	1.8	Dark red
Cone 1	6.5	18.3	1.2	Maroon flashes
Cone 4	6.4	17.9	0.6	Dark red
Cone 7	6.1	17.1	0.7	Maroon

Overburning temperature: About cone 8 (1,225°C. or 2,237°F.).
Best apparent burning range: Cone 06 to cone 1 (1,005°C. to 1,125°C. or 1,841°F. to 2,057°F.).
Total linear shrinkage at cone 02: About 12 to 13 per cent.
Deformation temperature: Cone 13 (1,350°C. or 2,462°F.).

In Brooklyn Township, Cuyahoga County, the Bedford shales are utilized for ceramic purposes at the Pearl Plant of the Cleveland Builders Supply & Brick Company, located about 1½ miles southwest of Brooklyn. The manufactured products consist of radial block for chimney and sewer work and hollow building block. The shale utilized is of the reddish-brown variety with a thickness of a little more than 20 feet. . . .

The shale was sampled on August 13, 1929. . . . The composition and physical tests of the sample are as follows:

Sample No. 46

Tests of Bedford shale from pit of Cleveland Builders Supply and Brick Co., Pearl Street plant, Cleveland, Cuyahoga County

Downs Shaaf, analyst

Chemical analysis

Water, hydroscopic H_2O-	1.96
Water, combined, H_2O+	5.45
Silica, SiO_2	57.20
Alumina, Al_2O_3	13.06
Titanic oxide, TiO_2	1.20
Phosphorus pentoxide, P_2O_5	0.15
Ferric oxide, Fe_2O_3	14.08
Ferrous oxide, FeO	1.36
Lime, CaO	0.65
Magnesia, MgO	1.62
Sodium oxide, Na_2O	0.35
Potassium oxide, K_2O	2.60
Manganese oxide, MnO	0.04
Sulfur, S	0.04
Carbon dioxide, CO_2	0.25
Carbon, organic, C	0.18

Oxide ratio

K_2O	.199				
Na_2O	.027				
CaO	.050				
MgO	.124			SiO_2	4.380
FeO	1.074	Al_2O_3	1.00	TiO_2	0.092
MnO	.003			P_2O_5	0.011
RO	1.477				

Physical properties, determined by Chester R. Austin

Properties in green state

Workability: This material is very plastic. A badly feather-edged column is extruded from the die.
Time of slaking: 128.47 minutes.
Water of plasticity: 22.03 per cent.
Dry shrinkage:
Volume: 16.59 per cent.
Linear: 5.25 per cent.
Drying behavior: This material dries satisfactorily with ordinary care.
Dry modulus of rupture: 427 pounds per square inch.

Cone	Apparent porosity (per cent)	Volume shrinkage (per cent)	Calculated linear shrinkage (per cent)
012	29.90	3.12+	1.0+
010	27.71	1.97	0.7
08	20.80	9.77	3.2
06	10.80	18.71	5.9
04	2.81	21.32	6.7

Cone	Absorption (per cent)	Bulk specific gravity	Apparent specific gravity
012	16.10	1.85	2.64
010	14.60	1.90	2.62
08	10.10	2.05	2.50
06	4.77	2.28	2.55
04	1.19	2.35	2.41

Fired modulus of rupture:
Cone 010, 2,291 pounds per square inch.
Cone 06, 4,611 pounds per square inch.
Fired specific impact strength:
Cone 09, 0.999 centimeter kilograms per square centimeter.
Cone 06, 0.46 centimeter kilograms per square centimeter.
Fired crushing strength: Cone 06, 4,241 pounds per square inch.
Best firing range: Cone 010 to cone 04.
Overfiring temperature: Cone 02.
Pyrometric cone equivalent: Cone 14-15
Scumming: Scumming takes place throughout the entire firing range of this material. One pound of $BaCO_3$ per ton of material is necessary to prevent scumming.
Salt glazing: This material does not withstand the temperature necessary for the development of a good salt glaze.
Utilization: This shale was being used for the production of radial block, fireproofing, and common brick. Another possible use is for drain tile. On firing the material develops a good red color at cone 04.

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The annotated bibliography incorporated in this paper is believed to be a comprehensive list of references to actual investigations of the Devonian-Mississippian shale sequence in Ohio. It is suggested that the reader utilize literature of the scientific societies, geological surveys of surrounding states, U. S. Geological Survey, and U. S. Atomic Energy Commission for supplemental reading.

The annotated bibliography is an outgrowth of bibliographic reference notes accumulated during the library research for the present paper. Thus, in selected instances the annotations may not convey the full essence of the work by the original writer. The annotated bibliography covers virtually all references up to January 1, 1956 concerning the problem of the Devonian-Mississippian shale sequence in Ohio.

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__________ 1865, Report on the economical geology of southern Ohio, traversed by the Marietta and Cincinnati Railroad, including the Portsmouth branch: Cincinnati, Ohio, Gazette Steam Printing House.

Discusses the black slate found below the sandstone of the Waverly group and its economic value for petroleum. Suggests the possibility of using it for oil distilling.

__________ 1871, Report of progress in the second district: Ohio Geol. Survey Rept. Prog. 1869, p. 55-142, map; another ed., p. 53-135, 1870.

Names the black shale of southern Ohio the "Ohio black slate".

__________ 1879, Proposed corrections for a part of the geological atlas, 1879, of Ohio: Am. Jour. Sci. (3), v. 18, p. 410.

Andrews notes the presence of black shale from the Ohio River north, whereas the atlas shows the Waverly rocks resting on the Silurian of the Cincinnati uplift without any intervening Devonian black shale (Huron shale of Newberry).

Appalachian Geological Society, 1937, Oriskany sand and Devonian shale, Appalachian area, in Oriskany sand symposium: Charleston, West Virginia, Appalachian Geological Society.

Map showing locations of "Brown shale" oil and gas fields.

Arnold, C. A., 1929, Petrified wood in the New Albany shale: Science (new ser.), v. 70, p. 581-582.

__________ 1931, On Callixylon newberryi (Dawson) Elkins and Weiland: Michigan Univ., Mus. Paleont. Contr., v. 3, p. 207-232, 9 figs., 7 pls.

Discusses the carbonized plant remains in the Ohio shale and cites anatomical evidence showing their identity with Callixylon newberri.

Arnold, C. A., 1934, The so-called branched impressions of Callixylon newberryi (Dawson) Elkins and Wieland and the condition of their preservation: Jour. Geology, v. 42, p. 71-76, 4 figs.

Historical summary of the plant material in the Ohio shale and discussion of its mode of preservation.

_________ 1937, Devonian and Mississippian plant-bearing formations in eastern America: Second Cong. Strat. Carbonifere Heerlen 1935, Comte Rendu, v. 1, p. 41-45, 1 pl.

_________ 1948, The Mississippian flora, in Weller, J. M., ed., Symposium on problems of Mississippian stratigraphy and correlation: Jour. Geology, v. 56, p. 367-372; (abs.) Geol. Soc. America Bull., v. 58, p. 1271, 1947.

Cautions future investigations in use of the New Albany flora age determinations of Read (1936), Read and Campbell (1939), and Campbell (1946).

Ashley, G. H., 1917, Oil resources of black shales of the eastern United States: U. S. Geol. Survey Bull. 641, p. 311-324; (abs.) Wash. Acad. Sci. Jour., v. 7, p. 564-565.

Reconnaissance investigation of oil shales of eastern United States, including study of two Ohio shale samples.

Austin, C. R., 1934, Surface clays and shales of Ohio: Ohio State Univ. Expt. Sta. Bull. 81, 53 p.

Preliminary report on the physical tests and properties, from a ceramic view, of the Devonian-Mississippian shales.

Baker, R. C., 1938, The age and fauna of the Olentangy shale of central Ohio: Iowa State Univ., Dept. Geol., Master's thesis (unpub.)

The fauna suggests a close relationship with the overlying Ohio shale and confirms Grabau's interpretation that the Olentangy is a basal facies of the Ohio shale.

_________ 1942, The age and fossils of the Olentangy shale of central Ohio: Am. Jour. Sci., v. 240, p. 137-143, 3 pls.

Wording nearly identical to that of Baker's Master's thesis (1938) but arrangement is different.

Ballard, Norval, 1938, Stratigraphy and structural history of east-central United States: Am. Assoc. Petroleum Geologists Bull., v. 22, p. 1519-1559, 3 figs.

Compares Ohio shale with its correlatives in other states. Correlations and cross sections are included.

Barrell, J., 1913; 1914, The Upper Devonian delta of the Appalachian geosyncline: Am. Jour. Sci. (4), v. 36, p. 429-472; v. 37, p. 87-109 and 225-253.

This paper, a comprehensive treatise dealing with the Catskill delta, is logically divided into three parts: 1, the delta and its relations to the interior sea; 2, factors controlling the present limits of the strata; and 3, the relations of the delta to Appalachia. Faunal, lithologic, depositional and paleogeographic aspects of the delta are considered.

Barthauer, G. L., Rulfs, C. L., and Pearce, D. W., 1953, Investigation of thucholite: Am. Mineralogist, v. 38, p. 802-14.

The rather unusual mineral thucholite contains about 50 percent carbon, 25 percent volatile gases, and 25 percent ash. The ash commonly consists of thoria, rare-earth oxides and uranium oxide.

Bassett, C. F., 1935, Stratigraphy and paleontology of the Dundee limestone of southeastern Michigan: Geol. Soc. America Bull., v. 46, p. 437-439.

Includes descriptions of Carman's unpublished sections of the "Blue limestone" strata exposed in the Silica and Whitehouse quarries.

Bassler, R. S., 1911, The Waverlyan period of Tennessee: U. S. Natl. Mus. Proc., v. 41, p. 209-224.
Correlates the Waverly series of Ohio with the formations of the same age in Tennessee. Regards the Chattanooga shale as equivalent to Cleveland, Bedford, Berea, and Sunbury of Ohio. Includes correlation chart.

__________ 1911a, The stratigraphy of a deep well at Waverly, Ohio: Am. Jour. Sci. (4), v. 31, p. 19-24.
Regards the Ohio shale as Mississippian in age.

__________ 1932, Stratigraphy of the central basin of Tennessee: Tennessee Div. Geol. Bull. 38, 268 p.
States that the Hardin and Chattanooga species are identical with species from the "Mississippian shale of northern Ohio"; however, does not provide conclusive evidence for this statement. Further states that the Chattanooga shale "in its western extension... maintains its character of a thin shale of Mississippian age, but in the northern states it overlaps older black shales which combined with it in Indiana and Kentucky are known as the New Albany shale and in Ohio as the Ohio shale".

Bassler, R. S., and Kellett, Betty, 1934, Bibliographic index of Paleozoic ostracoda: Geol. Soc. America Spec. Paper 1, p. 73-87.
Gives faunal lists of the Devonian and Mississippian formations.

Bayles, R. E., 1949, Subsurface Upper Devonian sections in southwestern Pennsylvania: Am. Assoc. Petroleum Geologists Bull., v. 33, p. 1682-1703.
Considers facies relationships of those units in Pennsylvania that have influence upon the Devonian-Mississippian shale sequence of Ohio.

Beck, R. W., 1934, Lower Mississippian formation of North America: Univ. Chicago, Master's thesis (unpub.)

Beers, R. F., 1945, Radioactivity and organic content of some Paleozoic shales: Am. Assoc. Petroleum Geologists Bull., v. 29, p. 1-22.
Black shales containing up to 16 percent organic matter have been found to contain high concentrations of uranium, thorium, and potassium (K^{40}). Excellent correlations exist between uranium content, uranium-thorium ratio, and carbon content in individual shale formations.

Berry, E. W., 1932, A remarkable specimen of Callixylon newberryi (Dawson) Elkins et Wieland, from the Ohio Shale: Ohio Jour. Sci., v. 32, p. 385-388, 2 figs.
Reports upon some plant impressions collected from the basal portions of Ohio shale north of Worthington, Ohio. These are referred to as the Callixylon newberri, though because of some aspects of their preservation Berry questions their genus affinity.

__________ 1939, Branching of Callixylon: Am. Jour. Sci., v. 237, p. 124-129.
Discusses the nature of branching of Callixylon.

Bond, R. H., 1937, A study of some conodonts from the lower part of the Ohio shale in central Franklin County, Ohio: Ohio State Univ., Master's thesis (unpub.)
The evidence for the age relationships of the lower Ohio shale is inconclusive.

__________ 1947, Ohio shale conodonts: Ohio Jour. Sci., v. 47, p. 20-37.
Systematic paper dealing with the conodonts collected from the lower unit of the Ohio shale in Franklin County, Ohio.

Bowen, C. H., 1951, Further studies of Ohio coals and oil shales; pt. III, Ohio shales and cannel coals: Ohio State Univ. Studies, Eng. Ser., v. 20, no. 1; and Eng. Expt. Sta. Bull. 143.

Discusses the Ohio shale potentialities for oil-shale use.

Bowlnocker, J. A., 1920, Geologic map of Ohio: Ohio Geol. Survey, (reprinted 1947 with revision of glacial boundary by G. W. White and with changes in base map; scale 1:500,000.)

__________ 1920a, Rise and decline in production of petroleum in Ohio and Indiana (abs.): Mining and Metallurgy, no. 158, sec. 22, 12 p., 2 figs.
States that the Ohio and Bedford shales form a great wedge-shaped mass with the apex in central Ohio and the base near Wheeling, W. Va., where its thickness is at least 2500 feet.

Bradley, W. H., 1933, Factors that determine the curvature of mud-cracked layers: Am. Jour. Sci. (5), v. 26, p. 55-71.

Branson, E. B., 1908, Notes on Dinichthys terrilli Newberry, with a restoration: Ohio Naturalist, v. 8, p. 363-369, 2 figs.
The Dinichthys terrilli remains described were recovered from the Ohio shale.

__________ 1911, Notes on the Ohio shale and its fauna: Missouri Univ. Bull., v. 2, p. 28.
Branson places the Devonian-Mississippian boundary at the top of the Bedford shale, because of the Bedford's close relationship to the underlying Devonian rock. He says the Ohio shale in northeastern Ohio has a distinct Devonian fauna at the top.

Branson, E. B., and Mehl, M. G., 1938, The conodont genus Icriodus and its stratigraphic distribution: Jour. Paleontology, v. 12, p. 156-166, 26 pls.
This genus is represented in the Devonian-Mississippian shales.

__________ 1940, The recognition and interpretation of mixed conodont fauna: Denison Univ. Sci. Lab. Jour., v. 35, art. 8, 15 p.; and Denison Univ. Bull., v. 40, p. 195-209.
Discusses Huddle's conodont zone in the New Albany of Indiana.

Breger, I. R. and Duel, Maurice, 1955, Geochemistry of uranium-bearing carbonaceous rocks in geologic investigations of radioactive deposits: U. S. Atomic Energy Comm., TEI-540, p. 186-188.
Data collected during research supports the conclusion that the uranium in the Chattanooga shale is present as a colloidal phase disseminated through the matrix as organic matter.

Breger, I. R., and Schopf, J. M., 1955, Germanium and uranium in coalified wood from upper Devonian black shale: Geochimica et Cosmochimica acta, v. 7, p. 287-293.
Some samples of the Cleveland shale coalified wood show enough detail to be identified with the genus Callixylon. The germanium is believed to have been part of the element constituents of the living wood. The wood probably absorbed uranium with the formation of organo-uranium compounds after replacement of the wood in the sediments. Tables give quantitative information on the component wood, ash, etc.

Briggs, C., Jr., 1838, First annual report: Ohio Geol. Survey, p. 77-80.
Refers to the Ohio shale as the "Argillaceous slaty rock, or shale stratum". The name Waverly sandstone series is given to all rocks lying between the "Argillaceous slaty rock or shale stratum (Ohio shale)" and "the Conglomerate".

Brown, J. C., 1904, Deposits on pipes and other channels conveying potable water: Inst. Civil Eng. Proc., v. 156, pt. 2, p. 1-17.

Suggests the color of black shales is due to a mixture of ferric hydroxide (or ferrous sulfide), manganese oxide, and organic matter.

Brown, R. W., 1949, Ecology of nonalgal marine plants: Natl. Research Council, rept. of the committee on a treatise on marine ecology and paleoecology, 1948-1949, no. 9, p. 105-110.
Discusses briefly the spread of land plants along shores of salt-water bodies and even into brackish and marine waters, and their usefulness in ecological studies. Includes annotated bibliography.

Bryant, W. L., 1921, The Genesee conodonts: Buffalo Soc. of Nat. Sci. Bull., v. 13, no. 2, 59 p., 7 figs., 16 pls.

Bucher, W. H., 1919, On ripples and related sedimentary surface forms and their paleogeographic interpretations: Am. Jour. Sci. (4), v. 47, p. 149-210, 241-269, 15 figs.
Gives paleogeographic interpretation of the Bedford-Berea ripples.

__________ 1933, Uber eine typesche kryptovulkanische Strorung in sudlichen Ohio: Geologische Rundschau, Saloman-Caloi Festschrift, v. 13a, p. 65-80.
The lower portions of the Ohio shale in southern Ohio constitute part of the Chautauguan series of Upper Devonian, whereas the overlying portion belongs to the Mississippian period (lower Waverlian).

Burroughs, W. G., 1911, the unconformity between the Bedford and Berea formations of northern Ohio: Jour. Geology, v. 19, p. 655-659
Discusses the anticlines and synclines of the area. The structuring of the Bedford-Berea in the area of investigation is post-Berea. A blue shale is found at the unconformity in many of the deep channels. Channels now filled with Berea sandstone were developed during the period when the Bedford horizon was above the level of the sea. The lower portion of these valleys became drowned, and the blue shale sediments were deposited; logically these blue shales belong to the Berea formation. The entire Bedford land area gradually was submerged, and the Berea sandstone formation was laid down.

Butts, Charles, 1922, The Mississippian series of eastern Kentucky: Kentucky Geol. Survey (6), v. 7, 188 p., 7 figs., 81 pls.
A discussion of the Bedford shale is included.

Cadman, W. H., 1948, The oil shale deposits of the world and recent development in their exploitation and utilization, reviewed to May 1947: Jour. Inst. Petroleum, v. 34, p. 109-132.
Reports that yields per ton of Upper Devonian shale from Kentucky and other eastern states are as follows: 16 gallons of oil and 58.6 pounds of $(NH_4)_2SO_4$.

Caley, J. F., 1943, Peleozoic geology of the London area, Ontario: Canada Dept. Mines and Resources, Mines and Geology Br., Geol. Survey Memoir 237 (no. 2470), 171 p., 4 pls., 5 figs.
The Kettle Point shale correlates with the upper part of the Ohio shale, the Hamilton with the Huron, and the Norfolk with the Delaware. Flora and fauna lists are given.

Campbell, Guy, 1946, New Albany shale: Geol. Soc. America Bull., v. 57, p. 829-908, 3 pls., 7 figs.
Reports on the Devonian-Mississippian shale sequence of Ohio as correlated with rocks of adjacent states, based upon a rapid reconnaissance survey, extrapolations from adjacent areas, and literature survey.

Campbell, M. R., 1898, Geologic atlas of the United States, London, Ky, folio: U. S. Geol.

Survey Geol. Atlas, Folio 47.
Notes that Bedford and Berea are absent in this area.

Carman, J. E., 1947, Geologic section of the Chillicothe test-core: Ohio Jour. Sci., v. 47, p. 49-54.
Describes the lithologic and paleontologic characteristics of the test core; makes no attempt to divide the Ohio shale into units.

________ 1955, Revision of the Chillicothe test-core section: Ohio Jour. Sci., v. 55, p. 65-72.
Describes a restudy of the core reported on by Carman in 1947; notes that the unit below the Olentangy shale is not Niagaran dolomite as reported, but Columbus limestone (as indicated by fossil evidence).

Carman, J. E., and Schillhahn, E. O., 1929, A new interpretation concerning the Hillsboro sandstone: Ohio Jour. Sci., v. 29, p. 169.
Reports on restudy of the Hillsboro sandstone, which is interpreted as including two types of deposits of the same age: (1) discontinuous sand deposits laid down on the post-Silurian erosion surface, and (2) sand that was washed down into existing cavities beneath this erosion surface. The Hillsboro is younger than the erosion interval (post-Greenfield dolomite deposition) and older than the Ohio shale. It is in the same hiatus as the Sylvanian sandstone of early Devonian age in northwestern Ohio.

________ 1930, The Hillsboro sandstone of Ohio: Jour. Geology, v. 38, p. 246-261, 8 figs; (abs.) Geol. Soc. America Bull., v. 40, p. 113-114, 250-251, 1929; (abs.) Pan-Am. Geologist, v. 51, p. 149.
Reaches the following conclusion concerning the Hillsboro sandstone: (1) The Hillsboro includes two types of deposits: bedded sandstone resting on either Niagaran or on the Greenfield dolomite, and cavity fillings enclosed in either the Niagaran or Greenfield dolomites. (2) It exists in a hiatus which extends from the Greenfield dolomite of Upper Silurian to the Ohio shale of Upper Devonian; the presence of black shale almost identical with the Ohio shale around the margins of some of the sandstone masses indicates that deposition of the sand took place just before the deposition of the Ohio shale. (3) In both physical and microscopic characteristics the Hillsboro is almost identical with the Sylvania sandstone of basal Devonian age in northwestern Ohio; the Hillsboro probably represents the finer portions of the Sylvania sandstone which shifted southward during the Silurian-Devonian erosion interval which in Highland County lasted until Late Devonian time.

Carney, Frank , 1909, A stratigraphic study of Mary Ann Township, Licking County, Ohio: Denison Univ. Sci. Lab. Bull., v. 14, p. 127-155, 15 figs.
Describes the stratigraphy, structure, and sedimentation of the Waverly group. The Bedford shale was deposited in the waters of a transgressing sea that was encroaching upon a land mass exposed to erosion for a long period of time. Bedford sediments were derived from a terrestrial source and delivered to the sea by a stream network. Thus, actually, they are terrestrial in origin.

Caster, K. E., 1934, The stratigraphy and paleontology of northwestern Pennsylvania: Am. Paleontology Bull., v. 21, no. 71, 185 p., 12 figs., 2 pls.
The purpose of Caster's study was to correlate the Upper Devonian and Lower Mississippian strata in northwestern Pennsylvania and adjoining parts of Ohio and New York. There is no geologic map, and much more of the report is devoted to a system of stratigraphic nomenclature proposed by Caster than to rock thickness and comparative stratigraphic sections. The discussion of the facies problems, however, is very significant for any consideration of the lithologic change in Ohio correlation units.

Caster, K. E., 1934a, Facies nomenclature and the Upper Devonian (abs.): Geol. Soc. America Proc. 1933, p. 348-349.

__________ 1935, Boundary between the Devonian and Mississippian systems in western Pennsylvania: Geol. Soc. America Proc. 1934, p. 441-442.
In northwestern Pennsylvania and northeastern Ohio the oldest Mississippian and youngest Devonian strata known in North America are found. The Cussewago sandstone is principally Late Devonian.

Chadwick, G. H., 1925, Chagrin formation of Ohio: Geol. Soc. America Bull., v. 36, p. 455-464.
Reconnaissance and literature survey plus extrapolations from adjacent areas concerned with the Chagrin and black shales of Ohio.

__________ 1933, (1) Great Catskill delta, and revision of late Devonic succession; (2) areal refinements; (3) revised correlations: Pan-Am. Geologist, v. 60, p. 91-107, 189-204, 275-286, 348-360.
The author believes a great unconformity is present at the base of the Cleveland shale, but no marked unconformity is known between the Cussewago sandstone and the underlying Chagrin shale.

Chamberlin, T. C., 1901, On the use of the term Bedford: Jour. Geology, v. 9, p. 267-270.
Reviews the various ways the word Bedford has been used in stratigraphic geology.

Clarke, J. M., 1886, Annelid teeth from the lower portion of the Hamilton group and from the Naples shales of Ontario County, New York: New York State Geol. Survey, 6th Ann. Rept. for 1886, p. 30-33, pl. A-1.
The three conodont species, Prionides angulatus, Hinde, P. erraticus, Hinde, and P. dubius, Hinde, are the only ones found in the Cleveland shale that are recorded from formations other than the Genesee and Hamilton horizons, thus indicating a Devonian age for the Cleveland shale.

__________ 1903, Naples fauna in western New York: New York State Mus. Rept. 57, v. 3, mem. 6, p. 199-201.

__________ 1915, Conceptions regarding the American Devonic: New York State Mus. Bull. 177, p. 115-133.
Reviews the "black shale problem". Concludes that the shales were deposited in a deep-water environment.

__________ 1917, Strand and undertow markings of Upper Devonian time as indications of the prevailing climate: New York State Mus. Bull., v. 196, p. 197-238.

Claypole, E. W., 1887, Preliminary note on some fossil wood from the carboniferous rocks of Ohio (abs.): Am. Assoc. Adv. Sci. Proc., 35th (Salem) meeting, 1886, p. 219-220.
Identifies two species of Dadoxylon (D. anlequius, Dawson, and D. newberryi, Dawson). The D. newberryi was collected from the Hamilton group (Olentangy shale?) in Highland County, Ohio.

__________ 1888, Fossil fish from the Ohio shale: Am. Geologist, v. 2, p. 62-64.
Summary of the fish fauna of the Cleveland shale and Cuyahoga shale (Berea shale of Orton).

__________ 1892, A new gigantic placoderm from Ohio: Am. Geologist, v. 10, p. 1-4, 1 fig.
Preliminary note on the description of Gorgonichthys clarki, Claypole.

__________ 1892a, The dentition of Titanichthys and its allies (abst.): Am. Geologist, v. 10, p. 193.

Describes the dentition of the Dinichthyidae and points out the peculiarities of the teeth of different fish genera.

Claypole, E. W., 1892b, The head of Dinichthys: Am. Geologist, v. 10, p. 199-207.
Uses a specimen of the skull of Dinichthys intermedius to describe the structure of this species and all the main characteristics of the whole genus.

__________ 1893, The Cladodont sharks of the Cleveland shale: Am. Geologist, v. 11, p. 325-331, 2 pls.; (abs.), Am. Naturalist, v. 27, p. 1083.
Systematic paleontological consideration of the sharks in the Cleveland shale.

__________ 1893a, The fossil fishes of Ohio: Ohio Geol. Survey, Vol. 7, p. 602-619, pls. 38-43.
Reports fish as being abundant in the Corniferous limestone and Cleveland shale, present in the Huron shale, and absent in the Hamilton and Erie shales. Anatomical and systematic treatise of many genera and species.

__________ 1893b, A new coccostean -- Coccosteus cuyahogae: Am. Geologist v. 11, p. 167-171, illus.
Describes a new fish from the lowest beds of the Cleveland shale, a horizon which had before that time yielded only an undescribed species of Titanichthys.

__________ 1893c, The three great fossil placoderms of Ohio: Am. Geologist v. 12, p. 89-99.
General account of the discovery of fossil fish in the Ohio shale.

__________ 1893d, On three new species of Dinichthys: Am. Geologist, v. 12, p. 275-279, pl. 12, 1 fig.
Dinichthys clarki, Claypole, and D. gracites, Claypole, are two of the species described; they came from the Cleveland shale.

__________ 1893 e, The Upper Devonian fishes of Ohio: Geol. Mag., v. 10, p. 443-448, illus.
Summary of the Devonian-Mississippian fish fauna.

__________ 1894, Cladodus? Magnificus, a new selachian: Am. Geologist, v. 14, p. 137-140, illus.
Identification, by inference, of a pair of mandibles found in a slab of Cleveland shale as those of a selachian.

__________ 1894a, On a new placoderm, Brontichthys clarki, from the Cleveland shale: Am. Geologist, v. 14, p. 379-380, 1 p.
Establishes this genus and species on the finding of a left jaw. No other material was found after diligent search.

__________ 1895, The great Devonian placoderms of Ohio: Geol. Mag. (4), v. 2, p. 473-474.
Brief synopsis of the genera Dinichthys, Titanichthys, Gorgonichthys, and Brontichthys, found in the Ohio shale. All are closely allied to Coccostius, and belong to the same family.

__________ 1895a, The cladodonts of the Upper Devonian of Ohio: Rept. Brit. Assoc. Adv. Sci., p. 695.
Reports that the species are limited to specific stratigraphic zones. Discusses evolutionary considerations of this fish. Notes that the fauna of the lower part of the Ohio shale in central Ohio (below the barren Erie shale) is different from that of the Cleveland shale.

__________ 1895b, On a new specimen of Cladodus clarki: Am. Geologist, v. 15, p. 1-7, illus.
By virtue of this new specimen, Claypole (1893) feels confident of his descrip-

tion of some fish remains he identified as C. clarki. This new specimen has its dentition preserved in practically its original position.

Claypole, E. W., 1896, The ancestry of the Upper Devonian placoderms of Ohio: Am. Geologist, v. 17, p. 349-360.

_________ 1897, A new Dinichthys -- Dinichthys kepleri: Am. Geologist, v. 19, p. 322-324, pl. 20.
A note mentioning the new find and comparing it with other species from the Ohio shale.

_________ 1903, The Devonian era in the Ohio basin: Am. Geologist, v. 32, p. 14-51, 79-105, 240-250, 312-322, and 335-353.
A comprehensive treatise of the Devonian era. Extensive bibliography provided. Exhaustive faunal lists. Fossils of the Huron, Erie, Cleveland, and Bedford shales are independently listed in a faunal chart on p. 249-250.

Cleveland Museum of Natural History, 1923, Fish of the black shale: Cleveland Mus. Nat. Hist. Bull. 8, p. 29-30.
Historical sketch of the fish remains in the Ohio shale.

_________ 1924, Extinct ocean fishes found in rocks near Cleveland: Cleveland Mus. Nat. Hist. Bull. 16, p. 61-63.
General consideration of the two types of fish (sharks and orthrodires) found in the Ohio shale.

_________ 1926, Harvesting fossils with an electric shovel: Cleveland Mus. Nat. Hist. Bull. 36, p. 141-142.
General treatment of Cladosilache specimens acquired by manmade trenching at Big Creek and West 128th Street, Cleveland, Ohio.

Clifton, H. E., 1956, The carbonate concretions of the Ohio shale: Ohio Jour. Sci., v. 57, p. 114-124, illus.
Report upon field, petrographic, and structural features of the carbonate concretions, with interpretation of their formation.

Collins, R. F., 1924, Pickeringite from the Cleveland shale: Columbia Univ., Master's thesis (unpub.)

Conant, L. C., 1952, Origin of the Chattanooga shale: U. S. Atomic Energy Comm., TEI-237, Oak Ridge, Tenn., 22 p.
Investigation of the geology and uranium content of the Chattanooga shale in Tennessee and parts of adjacent states.

_________ 1953, Chattanooga shale investigation: U. S. Atomic Energy Comm. TEI-330, Oak Ridge, Tenn., p. 145-146.
All recent analyses suggest that for a north-south airline distance of about 60 miles along the eastern Highland Rim, there is no great difference in uranium content.

Cone, C. and Rea, R. F., 1934, An investigation of the drying characteristics of Waverly shale: Ohio State Univ., B. Ceramic Eng. thesis, (unpub.), 22 p.

Cooper, C. L., 1931, Conodonts from the Arkansas novaculite, Woodford formation, Ohio shale and Sunbury shale: Jour. Paleontology, v. 5, p. 143-151, pl. 20.
From samples collected near Columbus, Ohio, from the Sunbury shale and top of the Ohio shale, the author concludes that the conodont fauna of the two formations is similar, and assigns a Mississippian age to the upper part of the Ohio shale.

Cooper, C. L., 1936, Actinopterygian jaws from the Mississippian black shales of the Mississippian Valley: Jour. Paleontology, v. 10, p. 92-94, 1 pl.
Specimens collected from the Cleveland shale near Ashmont, Ohio. Cooper regards the Cleveland shale as Lower Mississippian.

__________ 1948, Kinderhook micropaleontology, in Weller, J. M., ed., Symposium on problems of Mississippian stratigraphy and correlation: Jour. Geology, v. 56, p. 353-366; (abs.), Geol. Soc. America Bull., v. 58, p. 1272-1273, 1947.
"Black shale problem" of the New Albany shale areas is discussed.

Cooper, G. A., 1930, Stratigraphy of the Hamilton group of New York: Am. Jour. Sci. (5), v. 19, p. 116-134, 214-236, 6 figs; (abs.), Pan-Am. Geologist, v. 53, p. 146, 1930; (abs.) Geol. Soc. America Bull., v. 41, p. 116, 1930.
On a faunal basis Cooper suggests the correlation of the Prout limestone and Plum Brook as equivalent to rocks of Hamilton age in New York. He says Grabau's correlation of the Morse Creek is in error and that this formation is the westward equivalent of Techenor limestone.

__________ 1933, The Hamilton group of eastern New York: Am. Jour. Sci. (5), v. 26, p. 537-551, 3 figs; pt. 2, v. 27, p. 1-12, 1934; (abs.), Geol. Soc. America Bull., v. 44, p. 200-201, 1933; (abs.) Pan-Am. Geologist, v. 62, p. 156-157, 1934.
Fauna of New York Hamilton shales and Plum Brook shale closely agree.

__________ 1941, New Devonian stratigraphic units: Wash. Acad. Sci. Jour., v. 31, p. 179-181.
Proposes the name Plum Brook shale to replace Plum Creek shale of Grabau (1917). Grabau derived his name from Plum Brook, two miles northeast of Prout Station, Sandusky quadrangle, Ohio, but erroneously recorded the name as Plum Creek. The more accurate designation is therefore substituted.

Cooper, G. A., and others, 1942, Correlation of the Devonian sedimentary formations of North America: Geol. Soc. America Bull., v. 53, p. 1729-1794.

Cooper, G. A., and Warthin, A. S., 1942, New Devonian (Hamilton) correlations: Geol. Soc. America Bull., v. 53, p. 873-888.

Cooper, J. R., 1943, Flow structures in the Berea sandstone and Bedford shale of central Ohio: Jour. Geology, v. 57, p. 190-203, 13 figs. incl. index map.
Describes the flow structures studied in Delaware and Franklin Counties and concludes that they resulted from contemporaneous mass movements on the free surface of deposition.

Coryell, H. N., and Malkire, D. S., 1936, Some Hamilton ostracodes from Arkona, Ontario: Am. Mus. Novitates no. 891, 20 p., 38 figs.

Cottingham, Kenneth., 1927, Structural conditions in portions of eastern Ohio: Am. Assoc. Petroleum Geologists, v. 11, pt. 2, p. 945-958.

Cross, A. T., and Hoskins, J. H., 1951, Paleobotany of the Devonian-Mississippian black shales: Jour. Paleontology, v. 25, p. 713-728.
Reviews the Devonian-Mississippian black shale floral assemblages from the east-central interior of the United States and contrasts them with the typical Devonian and the pre-Pennsylvanian type of later Mississippian flora of North America. The flora of the New Albany and Ohio black shale complex is divisible into two groups, the Upper Devonian Callixylori Newberri-Foerstia - "Sporangites" type, and the Lower Mississippian flora of more than 25 genera (based on petrified wood fragments). Some conclusions based on the geographic distribution of these fossils and on the nature of the fossils themselves are discussed briefly.

Cross, A. T., and Hoskins, J. H., 1951a, The Devonian-Mississippian transition flora of east-central U. S.: Third Congress Strat. Carbonifere Heerlen, p. 113-122, illus.

Cumings, E. R., 1901, The use of Bedford as a formational name: Jour. Geology, v. 9, p. 232-233.

Cushing, H. P., 1912, The age of the Cleveland shale: Am. Jour. Sci. (4), v. 33, 581-584.
Proposes the name Olmsted shale as a fourth member of the Ohio shale for those beds designated by Kindle and others as the transition beds between the Cleveland and Chagrin. Says there is no real Sunbury in the section at Bedford, this horizon being marked by a few feet of a bright-colored shale, above which is the blackish Orangeville shale.

________ 1915, Diastrophic importance of the unconformity at the base of the Berea gr.: in Ohio: Geol. Soc. America Bull., v. 26, p. 205-216.
Holds that this so-called disconformity is merely contemporaneous erosion. In this paper he states certain conditions which should be present in order to indicate a gap of sufficient importance.

Cushing, H. P., Leverett, Frank., and Van Horn, F. R., 1931, Geology and mineral resources of the Cleveland district, Ohio: U. S. Geol. Survey Bull. 818, 138 p.
Gives stratigraphy, structure, geologic history, and economic use of the rocks in the Devonian-Mississippian shale sequence. Authors say that the Huron shale is not represented in the Cleveland section; they believe the Huron pinches out before getting as far east as Cleveland. Erosion of the Chagrin has produced an unconformable contact.

Daly, R. A., 1900, The calcareous concretions of Kettle Point, Lambton County, Ontario: Jour. Geology, v. 8, p. 135-150.
Discusses in some detail the probable mode of formation of the "kettles" (spherical concretions) present in the Kettle formation of Canada. States that these concretions occur in well-laminated bituminous shales and are pure calcium carbonate. They are spherical, have a radial structure, and have pushed the bedding planes apart. He states that the concretions were formed in place within the shale and antedate the period of joint development and final consolidation of the surrounding rocks.

Dawson, J. W., 1871, On spore-cases in coal: Am. Jour. Sci. (3), v. 1, p. 256-263.
Proposes the name Sporangetis Huronensis for the spore case observed by him in the Kettle Point shale, Lake Huron.

________ 1888, Geologic history of plants: London, Paul, Trench and Co., p. 1-290.
Notes the presence of Trilites and spinous and hooked spores or "sporangia" in the Bedford shale. Contrasts this variety of plant microfossils with the almost exclusive predominance of the abundant and widely disseminated Tasmanites, sporelike type in the Erian shales underlying the Bedford shale.

Dawson, J. W., and Penhallow, D. P., 1891, Notes on specimens of fossil wood from the Erian (Devonian) of New York and Kentucky: Canadian Rec. Sci., v. 4 (1890-91) p. 242-244.
The petrifaction flora of the New Albany flora was first considered by these authors in this paper.

Dean, Bashford, 1894, A new cladodont from the Ohio Waverly, Cladoselache newberryi, n. sp.: New York Acad. Sci. Trans., v. 13, p. 115-118, 1 pl.

________ 1901, On two new arthrodires from the Cleveland shale of Ohio: New York Acad. Sci. Mem., v. 2, p. 86-100, 5 pls., 2 figs.

Dean, Bashford, 1901a, On the characters of Mylostoma Newberry: New York Acad. Sci. Mem., v. 2, pt. 3, p. 101-109, pls. 7-8, 8 figs.

__________ 1902, The preservation of muscle fibres in sharks of the Cleveland shale: Am. Geologist, v. 30, p. 273-278, 2 pls.
Considers the chemistry of fossilization and environment of Cleveland shale deposition.

__________ 1909, Studies on fossil fishes (sharks, chimaeroids, and arthrodires): Am. Mus. Nat. Hist. Mem. v. 9, (5), p. 211-287, figs. 1-65, pls. 26-41.
Bases the youngest occurrence of the genus Cladoselache on the identification of a caudal fin. C. pachypterygins found in a phosphatic nodule from the base of the Waverly shale in Kentucky. This might be used for age correlation.

__________ 1909a, On the Arthrodire Trachostius clarki Newberry: Am. Mus. Nat. Hist. Mem. v. 9, (5), p. 272-276, p. 41, figs. 56-57.

DeWitt, Wallace, 1946, The stratigraphic relations of the Berea, Corry, and Cussewago sands in northeastern Ohio and northwestern Pennsylvania: U. S. Geol. Survey Oil and Gas Inv. (Prelim.) Chart 21.

__________ 1951, Strata of the Berea sandstone and associated rocks in northeastern Ohio and northwestern Pennsylvania: Geol. Soc. America Bull., v. 62, p. 1347-1370.
Summarizes the stratigraphy from Cleveland, Ohio, east into Pennsylvania.

DeWitt, Wallace, Demarest, D. F., and others, 1947, Map of the First and Second Berea sands of southeastern Ohio and western West Virginia: U. S. Geol. Survey Oil and Gas Inv. (Prelim.) Map 79.

Duggan, W. L., 1952, Description of a well core from Portage County, Ohio: Mich. Univ. M. S. thesis (unpub.), 47 p.
The Devonian-Mississippian shale section was not cored and therefore not logged, but the presence of Ohio and Hamilton shales is reported.

Dunkle, D. H., 1947, A new genus and species of Arthrodiran fish from the Upper Devonian Cleveland shale: Cleveland Mus. Nat. Hist. Sci. Pub., v. 8, no. 10, p. 103-117, 5 figs.
Systematic consideration of Bungartius perissus Dunkle.

Dunkle, D. H., and Bungart, P. A., 1939, A new Arthrodire from the Cleveland shale formation: Cleveland Mus. Nat. Hist. Sci. Pub., v. 8, no. 2, p. 13-28, 1 pl., 6 figs.
Systematic treatment of the arthrodire Gymnotrachelus hydei Dunkle and Bungart.

__________ 1940, On one of the least known of the Cleveland shale Arthrodira: Cleveland Mus. Nat. Hist. Sci. Pub., v. 8, no. 3, p. 29-47, 2 pls., 15 figs.
A study of Dinichthys clarki.

__________ 1942, The infero-gnathal plates of Titanichthys: Cleveland Mus. Nat. Hist. Sci. Pub., v. 8, no. 4, p. 49-59.
Describes the left infero-gnathal plates of T. agassizii Newberry and T. clarkii Newberry. A section of the paper is devoted to a comparison of Titanichthys with Dinichthys.

__________ 1942a, A new genus and species of Arthrodira from the Cleveland shale: Cleveland Mus. Nat. Hist. Pub., v. 8, no. 6, p. 65-71, 2 figs.
Systematic consideration of the new genus Holdenius, established in the paper.

Dunkle, D. H., and Bungart, P. A., 1943, Comments on Diplognathus mirabilis Newberry: Cleveland Mus. Nat. Hist. Sci. Pub., v. 8, no. 7, p. 73-84.

An addition to the original description based on the anterior half of one inferognathal plate collected from the Cleveland shale of Lorain County, Ohio.

__________ 1945, A new arthrodiran fish from Upper Devonian Ohio shale: Cleveland Mus. Nat. Hist. Sci. Pub., v. 8, no. 8, p. 85-95, 3 figs.

Systematic consideration of the Paramylostoma genus of Arthrodira from the Cleveland shale.

__________ 1945a, Preliminary notice of a remarkable arthrodiran gnathal plate: Cleveland Mus. Nat. Hist. Sci. Pub., v. 8, no. 9, p. 97-102.

Systematic treatment of the new species Dinognathus eurhinus Dunkle and Bungart.

Eastman, C. R., 1900, Dentition of some Devonian fishes: Jour. Geology, v. 8, p. 32-41, 7 figs.

Description includes dentition of Ohio's Corniferous fish.

Ehlers, G. M., Stumm, E. C., and Kesling, R. N., 1951, Devonian rocks of southeastern Michigan and northwestern Ohio: Ann Arbor, Mich., Edward Bros., Inc., Geol. Soc. America strat. field trip, Detroit meeting.

Describes stratigraphy, structure, and paleontology of the shale sequence represented in northwestern Ohio. Incorporates the Silica shale of Stewart with the "Blue" limestone of Carman (in Bassett, 1935) to make the Silica formation, which includes the entire interval between the Dundee limestone below, and Ten Mile Creek dolomite above.

Ehlers, G. M., and Wright, J. D., 1955, The type species of Spinocyrtia Fredericks and new species of this brachiopod genus from southwestern Ontario: Michigan Univ. Mus. Paleontology Contr., v. 13, no. 1, pl. 32.

Considers Hamilton group formations in Ontario that correlate with "Olentangy" equivalent units in Ohio.

Eisele, W. F., 1944, Cone-in-cone formation, Copperas Mountain, Ohio: Rocks and Minerals, v. 19, p. 39.

Describes cone-in-cone structure in the Ohio shale.

Elkins, M. G., and Wieland, G. R., 1914, Cordaitean wood from the Indiana black shale: Am. Jour. Sci. (4), v. 188, p. 65-78.

Compares specimens collected from the Devonian shales of Ohio with wood found in the New Albany shale.

Ellison, S. P., Jr., 1946, Conodonts as Paleozoic guide fossils: Am. Assoc. Petroleum Geologist Bull., v. 30, p. 93-110, 3 figs.

Contains charts, sketches, and stratigraphic ranges of 80 conodont genera. The Devonian aspects of the conodont fauna from the Ohio black shale and its correlatives are emphasized. The typical Ordovician conodont forms Acodus and Oistodus, described from the Olentangy shales, are interpreted as reworked specimens in a Devonian fauna.

Engineering and Mining Journal, 1955, Chillicothe is site of first uranium mine in Ohio: Eng. Mining Jour., v. 156, p. 166.

"Samples of ore (Ohio black shale) from the property owned by R. W. Mowery's O-Ky Mining Co., were assayed by the University of Maryland and reported favorable."

Evans, R. D., and Goodman, Clark, 1941, Radioactivity of rocks: Geol. Soc. America Bull., v. 52, p. 459-90.

Found that the average thorium-uranium ratio of source rock is close to 4.0. The observed value for the Antrim shale was about 8.0. This suggests that some selective agent has been at work tending to remove thorium from solution or colloidal suspension in excess of uranium.

Fenneman, N. M., 1927, Abstract of results, resources survey of the Commercial Club of Cincinnati: Univ. Cincinnati, Inst. of Sci. Research, ser. 2, no. 1, 86 p.
Reports that Bucher's early work on the oil shales from Pike County indicates no Ohio shale beds which yield more than 12½ gallons per ton; the average obtained was about 6 gallons per ton.

Fischer, W., 1906, Ecological observations on the flora of the shale bluffs in the vicinity of Columbus, Ohio: Ohio Naturalist, v. 6, p. 499-503.
The physiographic expression, erosion, and ground-water conditions control the flora of any one ravine cut in the Olentangy shales.

Fisher, R. A. B., 1941, Isopachous maps of the Appalachian geosyncline: Illinois Univ., B. A. thesis (unpub.), 15 p., 7 maps.

Foerste, A. F., 1891, The age of the Cincinnati anticlinal: Am. Geologist, v. 7, p. 97-109.
The anticlinal was not a source of sediments. Most of the sediments were derived from a continent east of the Alleghenies and from Canada.

__________ 1899, Age and development of the Cincinnati anticline (abs.): Science, v. 10, no. 8, p. 488.

__________ 1906, The Silurian, Devonian, and Irvine formations of east-central Kentucky, with an account of their clays and limestones: Kentucky Geol. Survey Bull. 7, 369 p.

__________ 1909, The Bedford fauna at Indian Fields and Irvine, Kentucky: Ohio Naturalist, v. 9, p. 515-523, pl. 1.
A Waverlian fauna was found below the Sunbury shale.

__________ 1935, Correlation of Silurian formations in southwestern Ohio, southeastern Indiana, Kentucky, and western Tennessee: Denison Univ. Bull., Jour. Sci. Lab., v. 30, p. 137-138.
The Hillsboro sandstone may represent the basal deposits of Lower Devonian and may be about the same age (Helderberg, Early Devonian) as the Sylvania sandstone of northern Ohio.

Foerste, A. F., and Morse, W. C., 1909, The Waverly formations of east-central Kentucky: Jour. Geology, v. 17, p. 164-177.
Shows that at Irvine, in northern Kentucky, the carboniferous fossils occur in beds which are the southern extension of the Berea, Bedford, and Sunbury formations of southern Ohio.

__________ 1912, Preliminary report on the Waverlian formations of east-central Kentucky and their economic values: Kentucky Geol. Survey Bull. 16, 76 p.
The report of a blue shale at the base of the Ohio shale in northern Kentucky suggests the extension of the Olentangy shale south of the Ohio River.

Foreman, Fredrick, and Thomsen, H. L., 1940, Textural and shape variations in the Berea sandstone of Ohio: Jour. Sed. Petrology, v. 10, p. 47-57.
In northern Ohio, Berea sandstone is fine grained and shows little variation in an east-west direction, but as the outcrop is followed southward, it becomes increasingly finer grained and grades into a siltstone in southern Ohio. The angularity is similar in all localities and grade sizes.

Gill, J. W., 1931, A study of colloids in Ohio shales and surface clays: Ohio State Univ., Dept. Ceramic, Eng., Ph. D. dissert., (unpub.), 46 p.

Girty, G. H., 1898, Description of a fauna in the Devonian black shale of eastern Kentucky: Am. Jour. Sci. (4), v. 6, p. 384-395.
Besides describing the fauna, Girty summarizes the literature pertaining to the Devonian age of the black shales of the eastern interior.

________ 1909, The Waverly group in northeastern Ohio: Science, (new ser.), v. 13, p. 664.
Cleveland and Bedford shales probably die out before reaching the Pennsylvania line.

________ 1904, Upper Paleozoic rocks in Ohio and northwestern Pennsylvania: (abs.). Science, (new ser.), v. 19, p. 24-25.
Proposes the name "Bradfordian" for the rock in southwestern New York lying between the Chemung and Waverly. This resulted from the comparison of sections of Paleozoic rock in Ohio and northwestern Pennsylvania.

________ 1905, The relation of some carboniferous faunas: Wash. Acad. Sci. Proc., v. 7, p. 1-26.
Regards the base of the Berea as the base of the Mississippian.

________ 1912, Geologic age of the Bedford shale of Ohio: New York Acad. Sci. Annals, v. 22, p. 295-319.
Concludes that faunally the Bedford is distinct from the underlying black shale as well as from the overlying Berea fauna. Girty believes the Devonian-Carboniferous boundary in northern Ohio should be placed at the top of the Bedford shale, because of the fact that this boundary is marked by an unconformity, by a basal sandstone, and by a pronounced faunal change.

Glenn, L. C., 1903, Devonian and Carboniferous formations of southwestern New York: New York State Mus. Bull. 69, p. 967-990.
This paper precipitated the dispute concerning the boundary line between the Devonian and Mississippian systems. Practically all subsequent work on these formations in New York, Pennsylvania, and Ohio has concerned this question.

Glennan, T. K., 1951, Address before Iowa Radio News Association Seminar, Iowa State College, Ames, Iowa, Sept. 28, 1951.
Expressed the view that recovery of uranium from shales (including Chattanooga shale) was not commercially feasible at the time of the address.

Gott, G. B., and Beroni, E. P., 1952, Uranium in black shales, lignites, and limestone in the United States, <u>in</u> U. S. Geol. Survey Circ. 220, p. 31-35.
Reports a uranium content for the Chattanooga shale ranging from 0.001 to 0.03 per cent.

Grabau, A. W., 1899, The paleontology of the Eighteen Mile Creek and the Lake Shore section of Erie County, New York: Buffalo Soc. Nat. Sci. Bull., v. 6, p. 150-158.
The conodont species <u>Pionedes angulaties</u> Hinde, <u>P. erratus</u> Hinde, and <u>P. dubius</u> Hinde, are the only species common to the Cleveland shale, and to Genesee and Hamilton strata. This fact indicates a Devonian age for the Cleveland shale.

________ 1906, Types of sedimentary overlap: Geol. Soc. America Bull., v. 17, p. 567-636; (abs.) Science, (new ser.), v. 21, p. 991-992, 1905.
Grabau was the first writer to suggest a Mississippian age for the Chattanooga shale. He regards the black shale region at the beginning of its deposition as a low, swampy peneplain. Since most of the underlying rock was limestone, it was readily soluble, leaving only a fine mud, colored black from the bituminous swamp material, as a soil cover. As the sea advanced over this area from the northwest, it reworked the black soil and deposited it as a basal black shale

unit. As the sea continued southward, the black mud zone also moved southward, thus becoming a time-transgressing unit.

Grabau, A. W., 1915, The Olentangy shale of central Ohio and its stratigraphic significance (abs.): Geol. Soc. America Bull., v. 26, p. 112.
States that Olentangy shale of central Ohio is intimately associated with the Huron (Ohio) shale and is probably Upper Devonian in age. Furthermore, considers the Olentangy shale of northern Ohio to be considerably older than that of central Ohio, probably early Hamilton, approximating the age of the Encrinal limestone of Eighteen Mile Creek, New York. Author proposes the name "Prout series" for the northern Ohio Olentangy.

__________ 1915a, North American continent in Upper Devonic time (abs.): Science, (new ser.), v. 41, p. 509-510; (abs.) Geol. Soc. Am. Bull. 26, p. 88-90, 1915.
Considers the paleogeography of North America. The river systems of Mississippian furnished black muds for the black shales deposited in embayments of diminished salinity. The eastern or Genesee beds are restricted to New York and the states just south. The base of the black shale of Ohio is younger than Genesee.

__________ 1917, 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. Geology, v. 25, p. 337-343.
Suggests the name Plum Creek shale for the interbedded shales and argillaceous limestone beneath the Prout limestone in the Plum Brook section. Grabau did not regard the Plum Creek shale and Prout limestone as equivalent to the Olentangy shale of central Ohio.

__________ 1917a, Stratigraphic relationships of the Tully limestone and the Genesee shale in eastern North America: Geol. Soc. America Bull., v. 28, p. 945-958; (abs.) p. 207-208.
West of Buffalo both the Tully and the Genesee are absent; Portage shales lie disconformably on the eroded surface of the Upper Hamilton. In northern Ohio, erosion in Upper Devonian time removed all beds above the Prout limestone. This erosion occurred before the deposition of the black Portage (Ohio) shale. This disconformity between the Ohio (Portage) shales and Hamilton beds is traceable throughout Ohio, Indiana, Kentucky, Michigan, Wisconsin, Illinois, and westward, becoming in general greater toward the south, thus implying that during early Late Devonian time the region west of New York was dry land and subject to erosion.

__________ 1919, Significance of the Sherburne sandstone in Upper Devonic stratigraphy: Geol. Soc. America Bull., v. 30, p. 465-468.
Dry land conditions prevailed in Ohio after the deposition of the Traverse formation of Hamilton age. This is evidenced by a marked disconformity between the Middle and Upper Devonic beds. Grabau postulates that the black Ohio muds were deposited in extensive estuaries. The depauperate and dwarfed faunas indicate dilution of the salt water by infusion of fresh water from rivers from the south.

Grossman, W. L., 1944, Stratigraphy of the Genesee group: Geol. Soc. America Bull., v. 55, p. 41-76.
Considers the microscopic petrography of these rocks.

Gutschick, R. C., 1947, Origin of some bitumen in the Devonian-Mississippian black shales and the Eocene Green River shale: Geol. Soc. America Bull., v. 58, p. 1185.
The Ozark dome, Nashville dome, and Cincinnati arch were regional oil structures. Erosion caused dissipation of the liquid bitumen. This oil was incorporated in the black muds to account in part for the bituminous content of the Devonian-Mississippian black shales.

Hale, Lucille, 1941, Study of sedimentation and stratigraphy of Lower Mississippian in western Michigan: Am. Assoc. Petroleum Geologists Bull., v. 25, p. 713-723.
Describes probable manner of development of typical Paleozoic shales. Lower Mississippian formations of western Michigan are the Coldwater, Ellsworth, and upper part of the Antrim formations. Western Michigan formations differ so markedly from those of eastern Michigan as to suggest different basins and different time of sedimentation.

Hall, James, 1843, Notes explanatory of a section from Cleveland, Ohio, to the Mississippi River in a southwestern direction, with remarks upon the identity of the western formations with those of New York: Assoc. Am. Geologists Rept., p. 267-293, 1 pl.

__________ 1860, Description of new species of fossils from the Hamilton group of western New York, with notice of others from the same horizon in Iowa and Indiana - Appendix F (Contributions to paleontology, 1858-59, with additions during 1860 to the 13th annual report of Regents of University of New York State on the conditions of the State Cabinet of Natural History): New York State Cabinet, Ann. Rept. 13, p. 92.
Allied to the "Hamilton problem" of Ohio.

__________ 1879, Descriptions of the gastropoda, pteropoda, and cephalopoda of the upper Helderberg, Hamilton, Portage, and Chemung groups: New York Geol. Survey, Paleontology, v. 5, pt. 2, 492 p.
Chonites lipidus and Styliola fissurella are described as being associated with each other in the black shales at Lexington, Ind., and in the Genesee shale of New York.

Hard, E. W., 1931, Black shale deposition in central New York: Am. Assoc. Petroleum Geologists Bull., v. 15, p. 165-181.
Describes probable manner of development for typical Paleozoic shales and reviews current theories of black-shale deposition. Hard believes the Upper Devonian bituminous shales of New York were deposited in comparatively shallow water, the source of sediments being on the east. During deposition of the black shale series a definite zone of demarcation was present between the shallow and comparatively fresh water of the east and slightly deeper and more saline water of the west. Bituminous content of the shales seems to be directly related to the type of organic material. This particular type of decay existed only where the water was truly saline and where toxic conditions were present.

Harker, D. H., 1944, Report to Ohio Water Supply Board on water supply in Summit County: Columbus, Ohio, Ohio Water-Supply Board, 81 p.
Stratigraphic consideration of the water-supply potentials of the Chagrin, Cleveland, and Bedford shales in Summit County.

Harper, A. R., 1948, Ohio in the making; a brief geologic history of Ohio: Columbus, Ohio State Univ., College of Education, 80 p.
A popular consideration of the Devonian-Mississippian shale sequence.

Harris, J. E., 1938, 1. The dorsal spine of Cladoselache; 2. The neurocranium and jaws of Cladoselache: Cleveland Mus. Nat. Hist. Sci. Pub., v. 8, no. 1.
Anatomic considerations of the Cladoselache.

__________ 1951, Diademodus hydei, a new fossil shark from the Cleveland shale: Zool. Soc. London Proc., v. 120, pt. 4, p. 683-697.

Hass, W. H., 1947, Conodont zones in Upper Devonian and Lower Mississippian formations of Ohio: Jour. Paleontology, v. 21, p. 131-141.
Suggests that the Bedford and Cleveland shales of northern Ohio are younger than the Blackiston formation but older than the Sanderson formation of Indiana.

Stratigraphic relationships of Huron shale and Cleveland shale members of Ohio shale to the undifferentiated Ohio shale of southern Ohio and to the Chagrin shale are partially still in question.

Concludes that: (1) There are five distinct conodont zones present in the formations that lie near the Devonian-Mississippian boundary in Ohio. (2) The Ohio shale contains two distinct conodont zones; the lower is equivalent to the Huron shale and the upper to the Cleveland shale. (3) Branson and Mehl's diagnostic Devonian and Mississippian conodont genera are, in the main, valid indicators of geologic age. (4) Campbell's Blackiston formation of Indiana is equivalent to the Huron shale, and his upper New Albany unit is a correlate of the Sunbury shale. The Bedford shale, Cleveland shale, and Olmsted shale member of the Cleveland shale are younger than Campbell's Blackiston formation but older than the Sanderson formation.

Hass, W. H., 1947a, The Chattanooga shale type area (Tennessee) (abs.): Geol. Soc. America Bull., v. 58, p. 1189.
The Chattanooga in the type area consists of three members: an upper black, a lower black, and a middle gray shale. The upper black shale member contains lower Mississippian conodonts and is correlated with the Sunbury shale of Ohio. The lower black shale contains conodonts that correlate with the Huron shale of Ohio, a formation that the U. S. Geological Survey classifies as Upper Devonian. The presence of Huron conodonts in the basal units of the Chattanooga disproves the thesis, held by some, that, as a unit, the Chattanooga shale is younger than the black shale sequence of the north-central states. The middle gray contains Huron conodonts, but its age is equivocal, as J. H. Swartz has reported macrofossils from it which he considers to be of early Mississippian age.

__________ 1956, Age and correlation of the Chattanooga shale and the Maury formation: U. S. Geol. Survey Prof. Paper 286, 5 pls. 1 fig., 8 tables.
Correlates the black shales by presence of conodonts. Reviews the correlation of Ohio shale with the Chattanooga. Regards the Chattanooga shale as Late Devonian, though the oldest beds of the formation could be late Middle Devonian. Maury shale is Mississippian (Kinderhook and possible Osage).

Heintz, A., 1931, The antero-lateral plate in <u>Titanichthys</u>: Annals and Mag. Nat. Hist., v. 8, p. 208-212, 3 figs.

__________ 1931a, A reconstruction of <u>Stenognathus gouldi</u> (Newberry): Annals and Mag. Nat. Hist., v. 8, p. 242-249, 5 figs.

__________ 1932, The structure of <u>Dinichthys</u>, a contribution to our knowledge of the <u>Arthrodira</u>: B. Dean Mem. vol., art. 4, p. 115-224, pls. 1-9, 91 text figs.

Hendrix, W. E., 1939, Ostracodes of the Olentangy shale of central Ohio: Ohio State Univ., Master's thesis (unpub.), 77 p.
Distinct ostracode faunas are found in northern and central portions of the Olentangy shale. The northern fauna is closely related to that of the Hamilton of Ontario and the Silica shale of northwestern Ohio. The fauna of central Ohio does not seem to be related to any known fauna.

Herrick, C. L., 1888, Geology of Licking County, Ohio, pt. 4, The subcarboniferous and Waverly groups: Denison Univ. Sci. Lab. Bull., v. 3, p. 13-110, 12 pls; (abs.) Am. Geologist, v. 3, p. 50, 1889; List of fossils continued: Denison Univ. Sci. Lab. Bull., v. 4, p. 100-106, 1888.
Divides the Waverly group into members based on paleontological evidence. Places the Devonian-Carboniferous boundary at the lowest part of the Black Hand formation, but suggests that the boundary might be even higher in the section.

Herrick, C. L., 1889, Notes upon the Waverly group in Ohio: Am. Geologist, v. 3, p. 94-99, 4 pls.
Discusses the age of the Waverly and the underlying and overlying units.

________ 1891, The Cuyahoga shale and the problem of the Ohio Waverly: Geol. Soc. America Bull., v. 2, p. 31-48.
Discusses the Bedford shale. States that the Bedford shale affinity lies with the underlying shales.

________ 1893, Observations upon the so-called Waverly group of Ohio: Ohio Geol. Survey Vol. 7, p. 495-515.

Hicks, L. E., 1878, Discovery of the Cleveland shale in Delaware County: Am. Jour. Sci. (3), v. 16, p. 70-71.
Says this Cleveland shale lies above the Berea grit as identified by N. H. Winchell. Hick's observation two miles east of Sunbury, however, was of the Sunbury rather than the Cleveland shale as he thought.

________ 1878a, The Waverly group of central Ohio: Am. Jour. Sci. (3), v. 16, p. 216-224.
Considers the stratigraphy of the strata lying between the Huron shale and base of thin coal measures.

Hinde, G. H., 1879, On conodonts from the Chazy and Cincinnati group of the Cambro-Silurian, and from the Hamilton and Genesee shale divisions of the Devonian, in Canada and U. S.: Quart. Jour. Geol. Soc., v. 35, p. 357-368.
Only three of the Cleveland shale species of conodonts thus far have been recorded in other formations. These are _Prionides angulatus_ Hinde, _Prionides erraticus_ Hinde, and _Polignathus dubius_ Hinde. These species are recorded only from the Hamilton and Genesee horizons elsewhere; therefore, the conodonts, so far as their evidence is recorded, indicate a Devonian age for the Cleveland shale.

Holden, F. T., 1942, Lower and Middle Mississippian stratigraphy of Ohio: Jour. Geology, v. 50, p. 34-67, 4 figs.
Gives a general areal description for the Bedford shale. A slight disconformity, marked largely by a sharp contact of contrasting shales, is present between the Bedford and the underlying Ohio shale. Fossils are found in the basal 3-30 inches of the Bedford, where they are rather common.

Holland, F. R., 1953, Some detailed sections of the New Albany shale near North Vernon, Indiana: Univ. Cincinnati, Master's thesis (unpub.).

Holmes, G. A., 1928, A bibliography of the conodonts, with descriptions of early Mississippian species: U. S. Natl. Mus. Proc., v. 72, art. 5, p. 1-38, pl. 1-11.

Hoskins, J. H., 1930, The genus _Callixylon_ in Ohio: Ohio Acad. Sci. Proc., v. 8, pt. 7, p. 410-411.

Hoskins, J. H., and Blickle, A. H., 1940, Concretionary _Callixylon_ from the Ohio Devonian black shale: Am. Midland Naturalist, v. 23, p. 472-481, 11 figs.
Describes structure and characteristics of the petrifications of nine specimens.

Hoskins, J. H., and Cross, A. T., 1947, Survey of certain Devonian-Mississippian transition flora., pt. I, Geological considerations; pt. II, Paleobotanical considerations: (abs.) Geol. Soc. America Bull. 58, p. 1194.

________ 1951, Petrifaction flora of the Devonian-Mississippian black shale: The Paleobotanist (Birbal Sahni Memorial Vol.), v. 1, p. 215-238.
An analysis of the longer ranging components of the petrification flora occur-

ring in the upper part of the New Albany-Ohio black shale of the east-central interior region of the United States. Clarifies the general character of the flora and determines the possible stratigraphic significance.

Hoskins, J. H., and Cross, A. T., 1951a, The structure and classification of four plants from the New Albany shale: Am. Midland Naturalist, v. 46, p. 684-716.
Considers taxonomy of some plants collected from the New Albany shale in Kentucky and Indiana that have affinities with the Ohio shale. Discusses Read versus Hoskins and Cross controversy over flora genera assignment and age establishment.

Hubbard, G. D., 1908, Rock terraces along the streams near Columbus, Ohio: Ohio Naturalist, v. 9, p. 397-402.
The Ohio shale was found to produce a terrace on a side stream.

Hubbard, G. D., Stauffer, C. R., Bownocker, J. A., Prosser, C. S., and Cumings, E. R., 1915, Description of the Columbus quadrangle, Ohio: U. S. Geol. Survey Geol. Atlas, Folio 197, 15 p.
Olentangy shale and Hamilton shale are equivalent. Ohio shale is equivalent to the Genesee, Portage, and Chemung formations. It is questioned whether the Bedford is Devonian or Mississippian in age.

Huddle, J. W., 1933, Marine fossils from the top of the New Albany shale of Indiana: Am. Jour. Sci. (5), v. 25, p. 303-314.

__________ 1934, Conodonts from the New Albany shale of Indiana: Am. Paleontology Bull., v. 21, no. 72, p. 1-136, pl. 1-12.
Suggests from study of conodonts that upper part of New Albany may be Mississippian and lower part Devonian. Gives faunal list. Deposition began in Genesee time in Indiana. <u>Callixylon newberryi</u> and Devonian brachiopods indicate the Devonian age for the New Albany shale up to within 5 or 10 feet of the top. The upper 5 or 10 feet affords the only likelihood of a zone of Mississippian age.

Hussakof, Louis, 1905, On the structure of two imperfectly known dinichthyids: Am. Mus. Nat. Hist. Bull., v. 21, p. 409-414, pls. 15-17, 2 figs.

__________ 1908, Catalogue of types and figured specimens of fossil vertebrates in the American Museum of Natural History. pt. I, Fishes: Am. Mus. Nat. Hist. Bull., v. 25, p. 1-103, pl. 1-6, 49 figs.

__________ 1911, Notes on some Upper Devonian <u>Arthrodira</u> from Ohio, U. S. A., in the British Museum (Natural History): Geol. Mag. (5), v. 8, p. 123-238, pl. 8, 3 figs.

Hutton, C. W., 1940, Geology of the Conneaut and Ashtabula quadrangles, Ohio: Ohio State Univ. Master's thesis (unpub.), 66 p.
Brief consideration of the Devonian-Mississippian shale sequence.

Hyde, J. E., 1911, The ripple of the Bedford and Berea formations of central and southern Ohio, with notes on the paleogeography of the epoch: Jour. Geology, v. 19, p. 257-269.
Discusses the Bedford formation. During Bedford deposition there was an open sea to the northeast.

__________ 1915, Stratigraphy of the Waverly formations of central and southern Ohio: Jour. Geology, v. 23, p. 665-682 and 757-779.
Discusses the probable age of the black shales and the Waverly strata. Notes that south of Lithopolis there is no pronounced unconformity at the base of the Berea.

__________ 1921, Geology of Camp Sherman quadrangle: Ohio Geol. Survey Bull. 23, 190 p., map.

Considers the stratigraphy, structure, and sedimentation of the Devonian-Mississippian shale sequence.

Hyde, J. E., 1926, Collecting fossil fishes from the Cleveland shale: Nat. Hist., v. 26, no. 5, p. 497-504.

__________ 1928, Fossil fishing in Cleveland shale: Cleveland Mus. Nat. Hist., Popular Pubs. v. 1, no. 1, 12 p.

__________ 1928a, Fossil fishing in Cleveland shales: Our Garden (Aug. and Sept. issue).

Hyde, J. E. (Marple. M. F., ed.), 1953, Mississippian formations of central and southern Ohio: Ohio Geol. Survey Bull. 51, 335 p., 54 pls.
Considers the stratigraphy, structural features, paleontology, and the Devonian-Mississippian contact in central and southern Ohio.

Illinois State Geological Survey, 1944, Symposium on Devonian stratigraphy, in Illinois Geol. Survey Bull. 68, p. 89-222.
Series of papers presented by distinguished authorities dealing with the Devonian stratigraphic units of Illinois and surrounding states.

Jackson, R. R., 1952, A petrographic study of the Middle Devonian limestone of central Ohio and the Bellefontaine outlier: Ohio State Univ., Dept. Geol., Master's thesis (unpub.).
The Columbus and Delaware limestones were studied in central Ohio and in the Bellefontaine outlier area. There formations were distinguishable by "residue" methods, etching, and thin sectioning. The insoluble constituents might be compared with the Hillsboro sandstone, Olentangy shale, and Ohio shale to see if the detrital matter in these units can be correlated with the underlying limestones.

Karhi, Louis, 1948, Cone-in-cone in the Ohio shale: Ohio State Univ., Master's thesis (unpub.), 55 p., 2 figs., 8 pls.
Demonstrates that cone-in-cone structures are present in lower, middle, and upper portions of the Ohio shale. These structures resulted from a calcareous ooze by diagenesis and were later affected by pressure and solution to form the cone-in-cone.

Kay, Marshall, 1951, North American geosynclines: Geol. Soc. America Mem. 48, 143 p.
Exhaustive treatise on the geosynclines of North America. The author's terminology is overwhelming even to the academic geologist.

Keele, Joseph, 1924, Preliminary report on the clay and shale deposits of Ontario: Geol. Survey Canada Mem. 142, 176 p., 11 figs., 9 pls.
Lithologic consideration of the Huron shale in Canada.

Kerr, T. H., 1948, Some studies of Ohio coals, shales, and oils: Ohio State Univ. Eng. Expt. Sta. Bull. 133, p. 32-44.
Considers the Ohio shale liquid fuel potentials.

Keyes, C. R., 1938, Age of Chattanooga black shales: Pan-Am. Geologist, v. 70, p. 364-366.
Keyes says the "Black Shales" may not be a stratigraphic formation. They may by an old oil-gathering zone, now almost dried up, which crosses the bedding indiscriminately, but which, when originally deposited, was parallel with an old erosion surface. In such case there would be great difficulty in working out any sort of nomenclature.

Kier, P. M., 1951, Echinoderms of the Silica shale: Michigan Univ., Master's thesis (unpub.).

Kindle, E. M., 1912, Unconformity at the base of the Chattanooga shale in Kentucky: Am. Jour. Sci. (4), v. 33, p. 120-136.

Discusses the previously adduced evidences for the age of the Devonian shales. The unconformity at the base of the Chattanooga shale does not transgress time as evidenced by his fieldwork. The Chattanooga in Kentucky represents the Huron as well as the high beds of the Ohio shale. The unconformity involved a time representing either early Genesee or late Hamilton, or both.

Kindle, E. M., 1912a, The stratigraphic relations of the Devonian shales of northern Ohio: Am. Jour. Sci. (4), v. 34, p. 187-213.
Extrapolation and reconnaissance - literature survey of northern Ohio black shale stratigraphy.

Klosky, Simon, 1955, Oil shale, in Mineral facts and problems: U. S. Bur. Mines Bull. 556 (preprint).

Krumin, P. O., 1949, Review of the Estonian oil shale industry, with a brief account of oil shale development in U. S.: Ohio State Univ. Studies, Eng. Ser., v. 18, no. 6, 125 p., 42 figs. 53 tables.
Considers the Ohio shale for its oil potential.

__________ 1951, Further studies of Ohio coals and oil shales, pt. I. Some studies of Ohio coals and oil shales: Ohio State Univ. Studies, Eng. Ser., v. 30, no. 1, and Eng. Expt. Sta. Bull. 143.
Considers the Ohio shale as an oil-shale possibility.

Krynine, P. D., 1940, Appalachian orogeny and sedimentation: (abs.) Soc. Geol. America Bull., v. 51, p. 1999.
The petrographic study of a fairly complete suite of Paleozoic sediments from central and western Pennsylvania resulted in the division of all Paleozoic formations into four recurring lithologic units: (1) graywackes and shales, (2) quartzic sandstone, (3) chemical and organic precipitates, and (4) unusual clastic rocks like calcarenites. It is shown that "identical" rock types recurring throughout the Paleozoic section were formed through reworking similar pre-existing older Paleozoic sediments. It follows that older Paleozoic formations were repeatedly re-elevated into the zone of erosion.

Lafferty, R. C., 1941, Central basin of Appalachian geosyncline: Am. Assoc. Petroleum Geologists Bull., v. 25, p. 781-825.
West of the epicontinental margin the Devonian "Brown shale" members merge to become the Ohio shale. East of this margin they are called just the "Brown shale members" of the "shale gas-producing area" of Kentucky, West Virginia, and Ohio. Suggests that the gas is confined in a fracture-type reservoir (vertical and horizontal fractures) near crest of anticlinal structure as well as on flanks and in the synclines. Fracture zones are probably more dependent on the hinge line created by differential settling along the lower margin of the epicontinental shelf than on other causes. The gray soft to siliceous shale, called by the drillers the "Big White", is the Olentangy shale. Suggests the Olentangy shale in the deeper parts of the basin might be one of the most important Devonian markers.

Lamborn, R. E., 1927, The Olentangy shale in southern Ohio: Jour. Geology, v. 35, p. 708-722.
Ohio shale is conformable on the Olentangy shale. Black shale conditions started during Olentangy time. If black shale beds constitute the dominant rock type, then the beds belong to the Ohio shale. Olentangy of northern and central Ohio is Middle Devonian (Erian). Either the Olentangy is of Late Devonian age in southern Ohio or the Ohio shale is Middle Devonian in central and southern Ohio. Concludes that the blue shale in southern Ohio is Olentangy shale, Olentangy shale is the basal phase of Ohio shale, and Olentangy shale is Late Devonian in age.

Lamborn, R. E., 1929, Notes on the character and occurrence of the Olentangy shale in southern Ohio: Ohio Jour. Sci., v. 29, p. 27-38, map.

________ 1934, Data on the thickness and character of certain sedimentary series in Ohio: Ohio Jour. Sci., v. 34, p. 345-364.
Discusses the Devonian-Mississippian shale sequence under the heading of the Big Lime-Berea series.

Lamborn, R. E., Austin, C. R., and Schaaf, Downs, 1938, Shales and surface clays of Ohio: Ohio Geol. Survey Bull. 39, 281 p., 4 pls., incl. geol. maps.
Comprehensive treatment of the ceramic qualities of rocks in the Devonian-Mississippian shale sequence.

Lane, P. J., 1950, A paleotectonic and paleogeologic study of the Mississippian system: Illinois Univ. M. S. thesis (unpub.), 70 p.

LaRocque, Aurèle, and Marple, M. F., 1955, Ohio fossils: Ohio Geol. Survey Bull. 54, 152 p.
Systematic paleontologic consideration of the Devonian and Mississippian fossils. Well illustrated.

Laswell, T. J., 1948, A textural analysis of the Bedford shale of Lorain County, Ohio: Oberlin College, A. M. thesis (unpub.)

Leeds. A. R., 1875, On an asphaltic coal from the shale of Huron River, Ohio, containing seams of sulfate of baryta: Annals Lyceum Nat. Hist., New York, v. 11, p. 105-106; (abs.) Am. Jour. Sci. (3), v. 10, p. 303, 1875.
Describes a coaly substance resembling the asphaltic coal or albertite of New Brunswick. The seams average about 2 inches in thickness and occur as fissures in the Huron shale throughout Ohio.

Lockett, J. R., 1927, General structure of the producing sands in eastern Ohio: Am. Assoc. Petroleum Geologists Bull., v. 11, p. 1023-1033.
Brief consideration of the Devonian-Mississippian shales.

________ 1937, The Oriskany sand in Ohio, <u>in</u> Oriskany sand symposium: Appalachian Geol. Soc., p. 61-65.
Says the oil and gas accumulation in Guernsey County on the Cambridge arch is not caused by the anticlinal structure, but rather that the eastward expansion of the Ohio shale is sufficient to compensate for the reversal of the beds above the Berea. Cross sections showing the structure of the Devonian-Mississippian shales.

________ 1947, Development of structures in basin areas of northeastern United States: Am. Assoc. Petroleum Geologists Bull., v. 31, p. 429-446, 4 figs.

Luther, D. D., 1903, Stratigraphy of Portage formation between the Genesee Valley and Lake Erie: New York State Mus. Bull. 69.
Good for correlation studies of Devonian units in Ohio.

McFarlan, A. C., 1943, Geology of Kentucky: Lexington, Ky., Kentucky Univ., 531 p.
Considers the stratigraphy and paleontology of the Devonian-Mississippian shale as represented in Kentucky.

McFarlan, A. C., and White, W. H., 1952, Boyle-Duffin-Ohio shale relationships: Kentucky Geol. Survey Bull. 10, p. 1-24.
Though the black shales are normally regarded as in an unconformable relation with the underlying formations, these authors appear to be able to demonstrate facies relations with the underlying carbonates.

McGregor, D. J., 1954, Stratigraphic analysis of Upper Devonian and Mississippian rocks in Michigan basin: Am. Assoc. Petroleum Geologists Bull., v. 38 p. 2324-2356, 17 figs.

Quantitative consideration of the shale sequence as represented in eastern Michigan, using isopach and lithofacies maps to serve as a basis for interpreting tectonic and environmental conditions and sedimentation processes. Concludes that tectonics of the depositional area are a very important factor in controlling sedimentary facies.

McKelvey, V. E., and Nelson, J. M., 1950, Characteristics of marine uranium-bearing sedimentation rocks: Econ. Geology v. 45, p. 35-53.

Study of marine black shales which are uranium-bearing. Many marine black-shale formations contain 0.01-0.02 percent uranium. Uranium-bearing marine black shales are rich in organic matter and sulfides, and contain little or no carbonate. The best are found in the thin formations of pre-Mesozoic age. The uranium in the marine sediments is syngenetic in origin, which is shown by the fact that uraniferous layers persist over thousands of square miles with little change in rock type or uranium content, and are interstratified with layers having markedly different composition. Uranium is found in the acid-soluble form in the sediments. Therefore, the immediate source of the uranium must have been sea water.

Martin, H. M., and Straight, M. T. 1956, An index of Michigan geology, 1823-1955: Michigan Geol. Survey Pub. 50, 461 p., charts, maps.

Bibliographic references to the Devonian-Mississippian strata of Michigan that may be correlated with similar units in Ohio.

Marvin, M. L., 1930, Cone-in-cone: Kentucky Univ., M. S. thesis (unpub.)

Mather, W. W., 1838, Remarks in addition to, and explanation of, the review of the report of the Geological Survey of Ohio (fossil bones and Waverly group): Am. Jour. Sci. (1), v. 34, p. 362-364.

Delineates the Waverly and the coal-measure red shale and sandstones.

__________ 1838a, First annual report on the Geological Survey of the State of Ohio: Columbus, Ohio, Samuel Medary, Printer to the State, 134 p; (abs.), Am. Jour. Sci. (1), v. 34, p. 347-362, 2 figs.

Describes the shale underlying the Waverly sandstone series as generally a black fissile shale with fetid odor, possessing masses of carbonate of lime as spheroid structures. Describes the Waverly sandstone series as consisting of alternating sandstones and shales with ripple marks.

__________ 1838b, Second annual report on the Geological Survey of the State of Ohio: Columbus, Ohio, Samuel Medary, Printer to the State, 286 p., map.

Briefly mentions rocks now referred to under the Devonian-Mississippian shales.

__________ 1859, Report on the Statehouse artesian well at Columbus, Ohio: Columbus, 41 p.; (abs.) Am. Jour. Sci. (2), v. 27, p. 276.

The well penetrates the lower part of the Devonian-Mississippian shale sequence.

Mathews, G. B., 1940, New Lepidostrobi from central United States: Bot. Gaz., v. 102, p. 26-49.

Describes a Lepidostrobus species from Ganard County, Ky. (This species is believed by Hoskins and Cross, 1951, p. 233, to be possibly from the Bedford formation).

May, P. R., 1950, Stratigraphic sections of the Plum Brook, Huron, and Chagrin shales of Middle and Upper Devonian age in Lorain County, Ohio: Michigan Univ., M. S. thesis (unpub.)

Stratigraphic and faunal log of a core. Fauna is identified only through genus (no species identification) in the case of the Chagrin and Huron shales. Prout limestone is absent.

Melcher, A. F., 1921, Determination of core specimens of oil and gas sands: Trans. Am. Inst. Mining Engineers, v. 65, p. 480-489.
Concerns Ohio shale in the Irvine oil field, Estell County, Ky. Porosity equals 7.6 to 7.4 percent.

Melvin, J. H., 1933, The geology of a portion of the Piketon, Ohio, quadrangle: Ohio State Univ., M. S. thesis, (unpub.), 47 p.
Areal study involving stratigraphy and structure of the shale series.

Mencher, Ely, 1939, Catskill facies of New York State: Geol. Soc. America Bull., v. 50, p. 1761-1789.

Miller, A. K., and Youngquist, Walter, 1947, Conodonts from the type section of the Sweetland Creek shale in Iowa: Jour. Paleontology, v. 21, p. 501-517, pls. 72-75.
Systematic paper on the Sweetland Creek shale with references to those species common to the Ohio shale and especially the Olentangy shale of Ohio.

Miller, Peter, Jr., 1944, A test of the Ohio shale for yield of oil: Ohio State Univ., Bachelor's thesis, (unpub.), 23 p.
Presents a series of quantitative assays for oil content. Main purpose of thesis was to develop the best extraction method to obtain optimum oil yield.

Miller, S. A., 1889, North American geology and paleontology: Univ. Cincinnati, 664 p., first appendix, 1892, p. 665-718; second appendix, 1897: p. 719-793.
A glossary of specific names in use in North American paleontology, p. 629-655.

Mining Engineering, 1951, Uranium -- swords or plowshares: Min. Eng. Jour., v. 3, p. 762-766.
Reports that the Chattanooga shale of Tennessee-Kentucky contains about 0.008 percent U_3O_8.

Moore, C. V., 1951, A petrographic study of the Columbus and Delaware limestones in Franklin and Delaware Counties: Ohio State Univ., M. S. thesis (unpub.), 55 p.

Morse, M. L., 1938, Conodonts from the Norwood and Antrim shales of Michigan: Michigan Univ., Ph. D. dissert., (unpub.)

Morse, W. C., and Foerste, A. F., 1909, The Waverly formations of east-central Kentucky: Jour. Geology, v. 17, p. 164-177.
Names the lower sandstone of the Bedford shale the Euclid sandstone lentil.

________ 1912, Preliminary report on the Waverlian formations of east-central Kentucky and their economic values: Kentucky Geol. Survey Bull. 16, 76 p.

Moses, C. F., 1922, The geology of the Bellefontaine outlier: Ohio State Univ., Dept. Geol., M. A. thesis (unpub.)
The Ohio shale reaches a thickness of nearly 200 feet in the hills east of New Jerusalem. Calcareous concretions are present in the basal 40 feet and cone-in-cone structures are found 120 feet above the base. Major systems of joints trend N. 40°W. and N. 55°E.

Nelson, B. W., 1955, Pre-Berea mineralogy and stratigraphy: Illinois Univ., Ph. D. dissert. (unpub.), 104 p.
Develops new facies concepts and sedimentation history of the Ohio and Bedford shales, based on clay mineralogical laboratory results and field investigation.

Newberry, J. S., 1857, New fossil fishes from the Devonian rocks of Ohio: Am. Jour. Sci. (2), v. 24, p. 147-149; Nat. Inst. Wash., D. C., (new ser.), v. 1, p. 119-126, illus.

__________ 1857a, On the deposits of the fossil fishes and reptiles of Linton, Ohio: (abs.) Edinburgh New Philos. Jour., (new ser.), v. 5, p. 364-365.

__________ 1860, The rock oils of Ohio: Ohio State Board Agriculture 14th ann. rept., p. 605-618; Advance sheet, 16 p., 1859. Utilization of the black shale.

__________ 1868, On some remarkable fossil fishes discovered by Rev. H. Harzer, in the black shale (Devonian) at Delaware, Ohio: Proc. Am. Assoc. Adv. Sci., v. 16, p. 146-147, 2 figs.

__________ 1868a, Geology (of Ohio) in Atlas of the State of Ohio: H. F. Walling, published for Henry S. Stebbins by H. H. Lloyd and Co., New York.

__________ 1870, Notes on some new genera and species of fossil fishes from the Devonian rocks of Ohio; Lyceum Nat. Hist. New York Proc., v. 1, p. 152.

__________ 1870a, Preliminary geological map of Ohio: Ohio Geol. Survey.

__________ 1871, Report of progress of the Geological Survey of Ohio in 1869: Columbus, Ohio, Nevins and Myers, State Printers, 176 p.

Named the Huron shales; called the Ohio shale group the Huron, Erie, and Cleveland shales. The Huron is regarded as Portage in age and the Erie as Chemung in age.

__________ 1871a, Sketch of structure of Lower Coal Measures in northeastern Ohio, pt. 1 of Report of progress of the (Ohio) Geological Survey in 1870: Columbus, Ohio, Nevins and Myers, State Printers, p. 5-14.

Makes reference to outliers of "Black Shale" in Highland County. Discusses the Huron shale.

__________ 1876, On an asphaltic coal from the shale of the Huron River, Ohio, containing sulfate of baryta: Annals Lyceum Nat. Hist. New York, v. 11, p. 105-106; and Am. Jour Sci. (3), v. 10, 1875, p. 303.

Adds a note to a paper by A. R. Leeds stating that the asphaltic coal described by Leeds occurs in the Huron shale and was formed from distilled petroleum, like the albertite and grahamite. Considers the Huron equivalent to the Portage group of New York geologists and says the Huron contains throughout from 10 to 25 percent carbonaceous matter, and is the source from which most of the oil is derived in both Pennsylvania and Ohio.

__________ 1878, Review of the geological structure of Ohio: Ohio Geol. Survey, Vol. 3, p. 1-51.

Places the Cleveland and "Erie" (Chagrin) shales in the Carboniferous system.

__________ 1879, Descriptions of new Paleozoic fishes: New York Acad. Sci., v. 1, p. 188-192.

__________ 1883, On the origin of carbonaceous matter in bituminous shales: Annals of New York Acad. Sci., v. 2, p. 357-369.

__________ 1883a, Fossil fishes from the Devonian rocks of Ohio: New York Acad. Sci. Trans., v. 2, p. 145.

__________ 1885, A cone-in-cone: Geol. Mag. (3), v. 2, p. 559-560.

__________ 1885a, The relations of Dinichthys, as shown by complete crania recently discovered by Mr. Jay Terrell in the Huron shale of Ohio: New York Acad. Sci. Trans., v. 3, p. 20.

Newberry, J. S., 1885b, Description of some gigantic pacoderm fishes recently discovered in the Devonian of Ohio: New York Acad. Sci. Trans., v. 5, p. 25-28.

__________ 1888, On the fossil fishes of the Erie shale of Ohio: (abs.), New York Acad. Sci. Trans., v. 7, p. 178-180.

__________ 1889, Devonian plants from Ohio: Jour Cincinnati Soc. Nat. Hist., v. 12, p. 53-55.

__________ 1889a, The Paleozoic fishes of North America: U. S. Geol. Survey Mon. 16, 340 p., 53 pls.; (abs.) Am. Jour. Sci. (3), v. 40, p. 355-356, 1890.

Newberry maintains a Waverly age for the Cleveland shale on the basis of three genera of carboniferous fishes, namely Hoplonchus, Orodus, and Polyrhizodus, (Kindle, 1912, p. 132-133, thinks Newberry confused the Sunbury with the Cleveland). Corrects his earlier mistake of confusing the two black shale members of the Ohio shale exposed near Lake Erie (calls them the same formation) and correctly places the "Erie" (Chagrin) between the two.

Newberry, J. S., and others, 1873, The general geological relations and structure of Ohio: Ohio Geol. Survey Vol. 1, pt. 1, p. 1-167.

Discusses relationship of the black shales to the structural studies of Ohio. Considers the shale series in the various county reports.

__________ 1873a, Report of the Geological Survey of Ohio; Paleontology: Ohio Geol. Survey Vol. 1, pt. 2, 399 p., Invertebrate fossils of the Devonian system described and figured; systematic treatment of the fossil fish and plants.

__________ 1874, Report of the Geological Survey of Ohio; Geology: Ohio Geol. Survey Vol. 2, pt. 1, 701 p.

Regards the Cleveland shale as Waverlian. Fails to recognize the Sunbury shale in southern Ohio but regards it instead as the Cleveland. Regards the Ohio shale proper of southern Ohio as Huron. Newberry's Erie shale is that which we now consider Chagrin. He discusses Devonian-Mississippian shale sequence by counties in which they crop out.

__________ 1874a, Report of the Geological Survey of Ohio; Paleontology: Ohio Geol. Survey Vol. 2, pt. 2, 435 p., 69 pls.

Systematic consideration of fossil fish, crinoidia from the Waverly group, and corals from the Devonian.

__________ 1878, Report of the Geological Survey of Ohio; Geology: Ohio Geol. Survey Vol. 3, pt. 1, 956 p. General geology by counties.

Newcombe, R. J. B., 1930, Middle Devonian unconformity in Michigan: Geol. Soc. America Bull., v. 41, p. 725-738, pls. 12-13, 4 figs.

The Michigan basin was the scene of shifting seas and the deposition of a variety of sediments during the Middle Devonian time. Middle Devonian formations in Michigan and Ontario show striking similarities, but corresponding formations in Ohio show decided thinning and disappearance of beds. Considers the "Olentangy shale" of the Michigan basin Middle Devonian.

__________ 1933, Oil and gas fields of Michigan; a discussion of depositional and structural features of the Michigan basin: Mich. Geol. Survey Bull., v. 38, 293 p.

Newman, K. R. and Woodhams, R. L., 1954, Stratigraphy and paleontology of a core from Lorain County, Ohio: Michigan Univ., M. S. thesis (unpub.).

Ohio Development and Publicity Commission, 1950, Ohio an empire within an empire: Columbus, Ohio, F. J. Heer Printing Co., 214 p.
Gives historical account of the use of the Ohio shale for distillation of kerosene and discusses future potentials of Ohio shale as an oil shale.

Ohio State University Engineering Experiment Station, 1943, Early history of hydrogenation of coal: Ohio State Univ. Eng. Expt. Sta. News, (Oct. 1943) p. 25-26.
Reprint of an article, "Coal oil, kerosene and petroleum (the early history of the manufacture of caro-hydrogen oil in the U. S.)" from Am. Mining Gaz. and Geol. Mag., v. 1., p. 110-112, 1864.
A footnote lists places in Ohio where such stills were located. One of the stills, near Buena Vista, Scioto County, used Ohio shale.

Orton, Edward, 1871, Geology of Highland County: Report of progress of the (Ohio) Geological Survey in 1870, p. 283-285, 306-307.
Names the Hillsboro sandstone from exposures in Highland County, Ohio. Assigns to it a thickness of 30 feet and describes it as resting upon the Niagaran limestone and overlain by either the Helderberg (Monroe) or by the Ohio shale. Calls it the highest member of the Niagaran series and interprets the sandstone as marking the beginning of the change from limestone and shaly limestone of the Ordovician and Silurian systems below to the sandstone and shale of the Devonian and Carboniferous system above.

__________ 1874, Report on third district: Ohio Geol. Survey Vol. 2, pt. 1, p. 611-696.
Geology of Ross and Pike Counties.

__________ 1878, Report on the geology of Franklin County: Ohio Geol. Survey Vol. 3, p. 596-646, map.

__________ 1879, Notes on the Lower Waverly strata of Ohio: Am. Jour. Sci. (3), v. 18, p. 138-140.

__________ 1882, A source of the bituminous matter in the Devonian and subcarboniferous black shales of Ohio: Am. Jour. Sci. (3), v. 24, p. 171-175.
Organic matter, which ranges from 8 to 21 percent, suggests that the vegetable spores were the contributors of the bituminous matter of the Ohio black shales.

__________ 1883, A source of the bituminous matter of the black shales of Ohio: Am. Assoc. Adv. Sci. Proc., v. 31, p. 373-384.

__________ 1885, The record of the deep well of the Cleveland Rolling Mill Company, Cleveland, Ohio: (abs.), Am. Assoc. Adv. Sci. Proc. v. 34, p. 220-222; <u>and</u> Am. Jour. Sci. (3), v. 30, p. 316.
The deep well penetrates part of the shale series.

__________ 1886, Preliminary report upon petroleum and inflammable gas: Ohio Geol. Survey, 76 p., 2 maps, (abs.) Am. Jour. Sci. (3), v. 32, p. 241, 1886; reprinted for the author with supplement, 200 p., pls., Columbus, 1887; (abs.) Am. Geologist, v. 1, p. 62-63, 1888.
Considers the stratigraphic aspects and petroleum and gas possibilities of the shale series.

__________ 1889, Discovery of sporocarps in the Ohio shale: (abs.), Am. Assoc. Adv. Sci., Proc., v. 37, p. 179-181.

__________ 1890, First annual report of the Geological Survey of Ohio (3rd organization): Columbus, Ohio, The Westbote Co., State printers.
Considers the stratigraphy of the Devonian-Mississippian shale series and evaluates the Ohio shale as a source of oil and gas.

Orton, Edward, 1899, The rock waters of Ohio: U. S. Geol. Survey, 19th Ann. Rept., pt. 4, p. 633-717, 3 pls.

Discusses ground-water potentialities of the Devonian-Mississippian shale sequence.

Orton, Edward, and others, 1888, Report of the Geological Survey of Ohio; Economic geology: Ohio Geol. Survey Vol. 6, 831 p.

Considers black shale in central Kentucky to be the upper or Cleveland division and gives the impression that this opinion is based upon physical criteria and faunal evidence. Considers the Ohio shale to be a source of oil and gas.

__________ 1893, Report of the Geological Survey of Ohio; Economic geology, archaelogy, botany, paleontology: Ohio Geol. Survey Vol. 7, 699 p., 56 pls.

Gives stratigraphical and paleontological consideration of the Devonian-Mississippian shale sequence.

Ostrom, M. E., Hopkins, M. E., White, W. A. and McVicker, L. D., 1955, Uranium in Illinois black shales: Illinois State Geol. Survey Circ. 203.

Discusses the black shales of Illinois that are equivalent to the Ohio shale.

Owen, D. D., 1859, Continuation of report of a geological reconnaissance of the shales of Indiana made in the year 1838: Indianapolis, Ind., pt. 2, p. 59.

Said that "The black slate in the base of these knobs [soft freestone knobs of Indiana] is the equivalent of the Scioto slates and shales." Prosser believed that Owen was referring to the shale later named the Ohio by Andrews.

Peattie, Roderick, 1923, Geography of Ohio: Ohio Geol. Survey Bull. 27, 137 p.

Refers to the economic utilization of the Devonian-Mississippian shale sequence in the ceramic and mineral-water industries.

Pedry, J. J., 1951, The geology of Chagrin Falls Township, Cuyahoga County, and Bainbridge Township, Geauga County, Ohio: Ohio State Univ., Dept. Geol., M. S. thesis (unpub.).

The Devonian-Mississippian shale sequence and lower part of the Berea are a marine deposit. The Bedford-Berea contact is the Devonian-Mississippian boundary.

Penhallow, D. P., 1896, <u>Nematophyton ortoni</u>, n. sp.: Annals Botany, v. 10, p. 41-49, pl. 5.

Pepper, J. F., Averitt, Paul, Demarest, D. F., and others, 1944, Map of the First Berea sand in southeastern Ohio and western West Virginia: U. S. Geol. Survey Oil and Gas Inv. (Prelim.) Map 9. (superseded by Map 79).

Pepper, J. F., Demarest, D. F., Holt, R. D., and others, 1944, Map of the Second Berea sand in Gallia, Meigs, Athens, Morgan, and Muskingum Counties, Ohio: U. S. Geol. Survey Oil and Gas Inv. (Prelim.) Map 5.

__________ 1945, Map of the Berea sand of southeastern Ohio, northern West Virginia, and southwestern Pennsylvania: U. S. Geol. Survey Oil and Gas Inv. (Prelim.) Map 29. (superseded by Map 89).

The basal siltstone of the Bedford appears greatly deformed and rolled into cylindrical shapes; the authors have called distorted siltstone flow rolls and the zone of deformation the flow-roll zone.

Pepper, J. F., Demarest, D. F., DeWitt, Wallace, Jr., 1945, Map of the Berea sand of northern Ohio: U. S. Geol. Survey Oil and Gas Inv. (Prelim.). Map 39 (superseded by Map 99).

Gives thickness of sand, location of oil and gas pools in the sand, structure sections, detailed maps, diagrams, and text.

Pepper, J. F., DeWitt, Wallace, Jr., and Demarest, D. F., 1954, Geology of the Bedford shale and Berea sandstone in the Appalachian basin: U. S. Geol. Survey Prof. Paper 259, 111 p., 14 pls., 61 figs; (abs.) Science, v. 119, p. 512-513, 1954.
Describes the genetically related Bedford and Berea and the superjacent rocks of Upper Devonian and Lower Mississippian age. Discusses the sedimentation and paleogeography of the Bedford and Berea, which makes up a cyclic depositional unit lying between the black shales (Ohio shale below and Sunbury shale above). The report sums up the results of an investigation made during World War II.

Pirtle. G. W., 1932, Michigan structural basin and its relationship to surrounding areas: Am. Assoc. Petroleum Geologists, Bull., v. 16, p. 145-152, 1 fig.
The Michigan basin is a structural and sedimentary basin which probably originated in Precambrian time. A low saddle occurs in the vicinity of Lake St. Clair between the basin and the Appalachian geosyncline.

Pohl, E. R., 1930, The black shale series of central Tennessee: Am. Jour. Sci. (5), v. 20, p. 151-152.
Divides the Chattanooga shale of central basin into three units, all separated by unconformities. The middle and upper units are considered Mississippian and are correlated with Cleveland and Sunbury shale, respectively. The lower unit is named Trousdale and is correlated with Genesee-Portage black shale. The author considers the Mississippian units very widespread, but the Devonian developed only locally.

Prosser, C. S., 1891, The geological position of the Catskill group: Am. Geologist, v. 7, p. 351-366.
Presents the paleontological evidence of many investigators for restricting the Catskill group. Many of the species cannot be used because of their wide range; for example, *Lepidodendron gaspianum* ranges from the Hamilton of New York to the subconglomerate of Ohio.

__________ 1901, On the Bedford shale and limestone of Ohio and Indiana: Jour. Geology, v. 9, p. 270-273.
A note on use of the name "Bedford" as a geological formation name.

__________ 1901a, The classification of the Waverly series of central Ohio: Jour. Geology, v. 9, p. 205-231.

__________ 1902, The Sunbury shale of Ohio: Jour. Geology, v. 10, p. 262-312 and 328, 6 figs.; and Ohio State Univ. Bull., ser. 6, no. 13, (Geol. ser. 3).
Discusses Newberry's confusion of the true Cleveland shale of northern Ohio with the Mississippian Sunbury shale of southern Ohio, which resulted in Newberry's placing many species in the Cleveland shale fauna that do not belong there.

__________ 1903, The nomenclature of Ohio geological formations: Jour. Geology, v. 11, p. 519-546; Ohio State Univ. Bull., ser. 8, no. 3, (Geol. ser. 6); (abs.) Geologisches Centralbl., band IV, 1904, p. 591-593.
Substitutes the name "Chagrin shale" for Newberry's term "Erie shale" as the middle member of the Ohio shale because the word "Erie" was preoccupied.

__________ 1903a, Notes of the Biological Club: Ohio Naturalist, v. 4, no. 2, p. 47.
Names the Prout limestone. The name Huron is not acceptable, having been applied in 1861 to a Michigan formation. The shale along the Vermilion River appears to be interfingered with the Ohio shale from the south.

Prosser, C. S., 1905, Revised nomenclature of the Ohio geological formations: Ohio Geol. Survey Bull. 7, 36 p.
This is virtually the same as Prosser (1903) paper.

_________ 1912, Devonian and Mississippian formations of northeastern Ohio: Ohio Geol. Survey Bull. 15, 574 p.; (abs.) Wash. Acad. Sci. Jour., v. 2, p. 352-353.
Discusses the stratigraphy, paleontology, structure, and correlation of the Devonian-Mississippian shale sequence of northeastern Ohio. Summarizes the controversies arising from the naming of the Upper Devonian and Lower Mississippian units. Concludes that the base of the Berea is the base of the Mississippian.

_________ 1912a, The disconformity between the Bedford and Berea formations in central Ohio: Jour. Geology, v. 20, p. 585-604.

_________ 1913, The Huron and Cleveland shales of northern Ohio: Jour. Geology, v. 21, p. 323-362.
Concludes from faunal and structural evidence that the Bedford was Devonian in age. The Chagrin shale lies between Huron and Cleveland shale and westward grades laterally into the Cleveland shale.

_________ 1916, The stratigraphic position of the Hillsboro sandstone: Am. Jour. Sci. (4), v. 41, p. 435-448; (abs.) Science, (new ser.), v. 43, p. 395.
Reviews Orton's work and gives sections of several of the exposures of the Hillsboro sandstone and associated formations in Highland County. Prosser does not definitely state his conclusion as to the stratigraphic position of the Hillsboro sandstone or give an interpretation of its origin, but on the basis of his sections one might conclude that the sandstone is interstratified in both the Cedarville and the Monroe divisions.

Prosser, C. S., and Cumings, E. R., 1904, The Waverly formations of central Ohio: Am. Geologist, v. 34, p. 335-361, 2 pls.

Province, Harold, 1952, Contemporaneous deformation in sedimentary rocks: Univ. Cincinnati, M. S. thesis (unpub.).
Discusses flow rolls found in the Berea sandstone (perhaps some of his localities are Bedford shale) at his stations 6, 7, and 8, which are located near Yankeetown, Waverly, and Gahanna, Ohio, respectively. At station 9, near Bucksville, Ohio, he describes these structures for the Euclid lentil of the Bedford formation. He concludes these structures result, in the main, from subaqueous sliding or gliding. Their main difference of appearance depends on (1) the extent to which sliding has progressed, (2) difference in competency of sediment due to differential cementation, (3) upward concavity at upper contact, suggesting sea floor deformation (4) contortions of the strata which were confined under their sediments, and (5) structuring due to facies phenomena.

Raymond, P. E., 1942, The pigment in black and red sediments: Am. Jour. Sci., v. 240, p. 658-669.
Suggests that the color of the Lower Paleozoic black shales is due to concentration of chitinous skeletal matter which drifted offshore from shallow water to open sea, where it was deposited with inorganic muds on the outer slopes below the depth of the profile of equilibrium. He believes that such chitinous skeletal matter was more abundant at that time than later.

Read, C. B., 1935, An occurrence of the genus Cladoxylon Unger in North America: Jour. Wash. Acad. Sci., v. 25, p. 493-497.

_________ 1936, A Devonian flora from Kentucky: Jour. Paleontology., v. 10, p. 215-227.
The flora of the basal part of the Linietta clay of Foerste at a locality near

Junction City, Ky., is described. Paleontologic and stratigraphic evidence indicates correlation of the Linietta clay with the upper part of the New Albany shale (Upper Devonian) of Indiana, and not the New Providence shale to which the whole of Foerste's Linietta has been attributed.

Read, C. B., 1937, The flora of the New Albany shale, pt. 2, the Calamopityeae and their relationships: U. S. Geol. Survey Prof. Paper 186E, p. 81-105.
Summarizes results of the examination of the Calamopityean forms. Includes an account of the species of Calaopetys, Stenomyclon, and Kalymma, all from the vicinity of Junction City, Ky.

Read, C. B., and Campbell, G., 1939, Preliminary account of the New Albany shale flora: Am. Midland Naturalist, v. 21, p. 435-453.
This paper is a treatment of the flora of the New Albany shale, its age, and its affinities. The complete flora is listed, and table showing species occurrences (for Kentucky and Indiana) is included. Systematic portion of the paper discusses several species not previously described. Shows that the flora of the New Albany shale is characterized by the occurrence of Psilophyta, Lepidophyta, Equisetalus, Cladoxylales, Sidarellales, and Pityeae. The flora indicates the presence of forms showing signs of earlier specialization than those in the Carboniferous.

Read, M. C., 1873, Report on the geology of Ashtabula, Trumbull, Lake and Geauga Counties, in Ohio Geol. Survey, Vol. 1, pt. 1, p. 481-533.
Traces the Bedford eastward to the State line.

Rector, Glasco W., 1950, Paleontology and stratigraphy of a well core from Ashtabula, Ohio: Michigan Univ. Master's thesis (unpub.), 37 p.
Thesis consists of a detailed lithologic and faunal log of a core starting in the Huron shale and bottoming in the Salina group.

Reeves, J. R., 1922, Preliminary report on the oil shales of Indiana: Indiana Dept. Conserv. Pub. 21, pt. 6, p. 1059-1105.
Reports on the New Albany shale.

__________ 1923, A section through the New Albany shale: Indiana Dept. Conserv., 4th Ann. Rept., p. 18-21.
Normal thickness of New Albany is a few feet less than 100 feet. Top 35 feet and lower 20 feet of the core analyzed yielded the high oil content. The oil-forming matter is probably of the same composition all through the 100 feet of the formation, as indicated by the very small variation in specific gravity. Average yield of oil for the core analyzed is 8. 3 gals. per ton.

__________ 1923a, Oil shales of Indiana: Indiana Univ., Dept. Geol., 92 p. (mimeo.)

Rich, J. L., 1948, Probable deep-water origin of the Marcellus-Ohio-New Albany-Chattanooga black shale (abs.): Geol. Soc. America Bull., v. 59, p. 1346-1347.

__________ 1951, Probable fondo origin of Marcellus-Ohio-New Albany-Chattanooga bituminous shales: Am. Assoc. Petroleum Geol. Bull., v. 35, p. 2017-2040, 1 fig.
Lists and discusses views of various authorities on deep- and shallow-water origins of black shales.

Rich, J. L., and Wilson, W. J., 1950, Paleogeographic and stratigraphic significance of subaqueous flow markings in the Lower Mississippian strata of south-central Ohio and adjacent parts of Kentucky: (abs.), Geol. Soc. America Bull., v. 61, p. 1496.
Flow marks appear as casts on the underside of Lower Mississippian siltstone beds. These marks are interpreted as having been made on the underlying shales by density currents of silt-laden water flowing down a foreset slope (clinoform) being built westward into deeper water during time of deposition.

Rivière, André, 1947, Contribution a l'etude des sediments argileux: France Soc. Geol., Bs. 5, t. 16 (1946), figs. 1-3, p. 43-55, illus.
The clay minerals produced during weathering of acid rock by acid waters rich in humic materials generally belong to the kaolin group. Weathering of most igneous and crystalline rocks, under normal pH conditions, usually re-results in the formation of minerals belonging to the illite-braviasite group.

__________ 1953, Sur l'origine des argiles sedimentaires: Internat. Geol. Cong., 19th, Algiers, v. 18, p. 177-180.
The kind of clay minerals found in argillaceous sediments depends not only on the conditions which existed in the deposition, but also on the nature of the transported material.

Rivière, André, Salle, Claude, and Vernhet, Solange, 1951, Sur certaines anomalies granulometriques apparentes des roches argileuses et leur interpretations geologique: Paris Acad. Sci., C. R. t. 232, no. 20, p. 1858-1860, illus.
Argillaceous rocks of various grain sizes are in many instances much richer in extremely fine material than are fine-grained argillaceous rocks. This is due to differences in the conditions of deposition.

Rivière, André, and Vernhet, S., 1951, Sur la sedimentation des mineraux argileux en milieu marin en presence de natieres humiques; consequences geologiques: Paris Acad. Sci., Compte Rendus, v. 233, p. 807-808.
The presence of small amounts of humic matter makes kaolin clays much more resistant to flocculation by sea water.

Rogers, J. K., 1933, Geology of Highland County, Ohio: Univ. Cincinnati Ph. D. dissert., 536 p., map; Ohio Geol. Survey Bull. 38, 148 p., map.
Stratigraphy and paleontology of the shale sequence.

Rogers, W. B., and Rogers, H. D., 1842 and 1843, Observations on the geology of western peninsula of upper Canada and western part of Ohio: Am. Philos. Soc. Proc., v. 2, 1842, p. 120-125, also Am. Philos. Soc., Trans., v. 8, (new ser.), 1843, p. 273-284.

Romenger, C., 1873-1876, Black shales of Michigan: Michigan Geol. Survey Vol. 3, p. 63-67.

__________ 1876, Black shales of Ohio-Genesee shales of New York: Michigan Geol. Survey Vol. 3, pt. 1, p. 65-68.

__________ 1876a, Waverly group: Michigan Geol. Survey Vol. 3, pt. 1, p. 69-101.

Rubey, W. W., 1929, Origin of the siliceous Mowry shale of the Black Hills region: U. S. Geol. Survey Prof. Paper 154-D, p. 153-170, 3 pls.
Field, chemical, and microscopic evidence indicates almost certainly that the silica in the Mowry shale was in some way derived from the alteration of volcanic ash. It is suggested that the original ash was decomposed by long exposure to sea water, and that silica dissolved from it was precipitated by decaying organic matter. A minor amount of secondary silicification may have occurred during consolidation and weathering. This paper is a very good analytical study, which could serve as a basis for a similar study of the Devonian-Mississippian shale sequence.

Ruedemann, R., 1934, Conditions of black shale accumulation and general conclusions: Geol. Soc. America Mem. 2, p. 43-64.
Concerned specifically with graptolite-containing shales. Summarizes prevailing interpretations of black-shale deposition. The noncalcareous black-shale fauna is very unlike that of the limestones and calcareous shales which are found in the same area.

Ruedemann, R., 1935, Ecology of black mud shales of eastern New York: Jour. Paleontology, v. 9, p. 79-91.
Reviews conditions for deposition of black shale. Controlling factors are dearth of oxygen and accumulation of organic matter faster than it can be oxidized. The conclusion is reached that the deposition of black shales extended over large areas and continued for a long time. The locus was at the deeper levels of the littoral zone or at the bottom of troughs where currents could bring in the plankton fauna freely.

Ryan, E. M., 1943, Conodonts from the Hardin sandstone of Tennessee: Missouri Univ., M. S. thesis, (unpub.).
Some conodont species in the Hardin sandstone are common to the Ohio shale.

Sappenfield, L. W., 1950, Magnetic survey of Adams County cryptovolcanic structure: Univ. Cincinnati, M. S. thesis, (unpub.).

Savage, T. E., 1930, Devonian rock of Kentucky: Kentucky Geol. Survey, ser. 6, v. 33.
Gives conclusions concerning age of the New Albany: (1) New Albany deposition began as early as Tully time. (2) No break or hiatus in sediments exists in lower part or, in fact, any part. (3) Though deposition began at different times at different places (because of "Duffin layers"-- a dolomitized limestone) the rock types are similar on both sides of Cincinnati arch.

Sayles, R. W., 1923, Seasonal deposition in marine waters: Natl. Research Counc., Div. Geol. and Geog., Comm. Sedimentation Rept. (1922-1923), p. 61-64.
Describes experiments to determine actual conditions of deposition in salt water, rate of settling of clay particles in fresh and salt water. Considers the importance of temperature, density, wind, bottom currents, and shape of basin, with reference to deposition study.

Scharff, R. F., 1911, Distribution and origin of life in America: London, 496 p., maps.
Some paleogeographic maps.

Schillhahn, E. O., 1929, A restudy of the Hillsboro sandstone of Highland County: Ohio State Univ., M. A. thesis, (unpub.).

Schopf, J. M., 1953, Organic matter of the Chattanooga shale: U. S. Atomic Energy Comm. TEI-330, p. 146-152.
The general relationship reported between organic content and radioactivity suggests an additional possible means of determining whether a similar relationship exists within the laminae. This is studied with nuclear-type autoradiographic films to determine (1) whether radioactivity is distributed in accordance with the evident lamination, and (2) whether any pattern having microstratigraphic significance may be observed (exposure periods of several months are required for sufficient track density to be recorded on the film). Organic matter includes: Foerstia - a group of planktonic marine algae that may be distantly related to modern Phaeophycae, Callixylon - (as drift wood) both as silicified and as bituminous coaly streaks - some of these are unusually radioactive, Protoaxites -- (rarely identified) a large algoid plant; some of these individuals are unusually radioactive.

Schopf, J. M., Wilson, L. R., and Bentall, Ray, 1944, An annotated synopsis of paleozoic fossil spores and the definition of generic groups: Illinois Geol. Survey, Rept. Inv. 91, p. 1-72
Paleobotanical consideration of Devonian and Mississippian systems.

Schuchert, Charles, 1910, Paleogeography of North America: Geol. Soc. America Bull., v. 20, p. 420-606.
Treatment of the paleogeography during the Devonian-Mississippian shale sequence deposition in Ohio.

Schuchert, Charles, 1910a, Biologic principles of paleogeography: Pop. Sci. Monthly, p. 591-560.

Carbonaceous matter of black shales may be of algal origin, but it is far more probable that it is largely of animal origin as suggested by the optical properties which compare with those of animal oil, especially those of fish oil.

__________ 1915, The conditions of black shale deposition as illustrated by Kupferschiefer and Lias of Germany: Am. Philos. Soc. Print. no. 54, p. 259-269.

States that widely distributed black shales probably originated in closed arms of the sea, cul-de-sacs, and that some bituminous shales may be the result of "sargasso seas."

__________ 1923, Sites and nature of the North American geo-synclines: Geol. Soc. America Bull., v. 34, p. 151-230.

__________ 1943, Stratigraphy of the eastern and central United States: New York, John Wiley and Sons, Inc., p. 564-570.

Discusses the stratigraphy of Upper Devonian and Lower Mississippian of Ohio. Faunal evidences and controversies of correlations are briefly noted.

__________ 1955, Atlas of paleogeographic maps of North America: New York, John Wiley and Sons, Inc., 177 p.

Map 35 (Middle Devonian - Marcellus) through Map 40 (Lower Mississippian-Middle Kinderhookian) are concerned with the Devonian - Mississippian shale sequence.

Scott, D. H., and Jeffery, E. C., 1914, On the fossil plants showing structure, from the base of the Waverly shale of Kentucky: Royal Soc. [London] Philos. Trans. (ser. B), v. 205, p. 315-373.

Reports on the study of the plants collected from the base of the Waverly shale at Linietta Springs, near Junction City, Ky.

Seyfried, C., 1953, Concretions as indicators of compaction of the Ohio black shale, southern Ohio: Univ. Cincinnati, M. S. thesis, (unpub.)

Shaler, N. S., 1877, Notes on the investigations of the Kentucky Geological Survey during the years 1873, 1874, and 1875: Kentucky Geol. Survey, Rept. Prog., v. 3, p. 129-282.

Contains many references to the black shales pertaining to their economic value for building stone, oil content, etc. On page 169 Shaler proposes the name "Ohio shale" for this black shale which Andrews (1871) called "Ohio black shale." Regards the Ohio shale as a deep-water deposit.

Shimer, H. W., and Shrock, R. R., 1944, Index fossils of North America: New York, John Wiley and Sons, Inc., 837 p., pls. 1-303.

Siebenthal, C. E., 1901, On the use of the term Bedford limestone: Jour. Geology, v. 9, p. 234-235.

Smith, R. C., and White, G. W., 1953, The ground-water resources of Summit County, Ohio: Ohio Div. Water Bull. 27, 130 p.

Stratigraphic character of the Devonian and Mississippian systems.

Stanfield, K. E., and Frost, I. C., 1949, Method of assaying oil shale by a modified Fischer retort: U. S. Bur. Mines Rept. Inv. 4477.

Accepted laboratory method for assaying oil shales.

Stauffer, C. R., 1907, The Hamilton in Ohio: Jour. Geology, v. 15, p. 590-596.

Olentangy of northern Ohio is perhaps of Hamilton age.

Stauffer, C. R., 1907a, The Devonian limestones of central Ohio and southern Indiana: Ohio Naturalist, v. 7, p. 184-186.

Correlation of the two regions lying on opposite sides of the Cincinnati island shows the Delaware limestone is correlative with the Sillersburg beds of Indiana.

__________ 1908, The Devonian section on Ten Mile Creek, Lucas County, Ohio: Ohio Naturalist, v. 8, p. 271-276.

Stratigraphy and paleontology of the artificially exposed section along Ten Mile Creek.

__________ 1909, The Middle Devonian of Ohio: Ohio Geol. Survey Bull. 10, 204 p.

Stratigraphic and faunal consideration of the Delaware limestone. Treatment of the shale series.

__________ 1913, Geology of the region around Hagersville (Ontario): Internat. Geol. Cong., 12th, Canada, Guide Book 4, p. 82-99.

Considers the Devonian shales of Ontario.

__________ 1915, The Devonian of southwestern Ontario: Canada Geol. Survey Mem. 34, p. 9-10.

Correlates the Plum Brook shale with the basal shales overlying the Delaware limestone (Arkona shale) exposed at Arkona and Thedford, Ontario.

__________ 1916, The relationships of the Olentangy shale and associated Devonian deposits of northern Ohio: Jour. Geology, v. 24, p. 476-487.

Correlates Olentangy with blue-gray Hamilton shales in Ontario and tentatively agrees with Grabau's correlation of the Olentangy with the encrinal limestone of Eighteen Mile Creek, New York. Stauffer points out, however, an apparent unconformity between Olentangy of central Ohio and overlying Ohio shale. He says Huron shale (or lower part of Ohio shale) rests unconformably on the Prout limestone in northern Ohio, on Olentangy in central Ohio, and locally on the Silurian limestone in southern Ohio. Considers the black shale to be disconformable on the underlying beds.

__________ 1938, Conodonts of the Olentangy shale: Jour. Paleontology, v. 12, p. 411-443, pls. 48-53.

Lists 118 species of conodonts of 88 different samples from 23 localities, including two in Ontario and one in Kentucky. Twenty-one of these are from the "Olentangy" shale in northern Ohio and 101 from the Olengangy shale in central Ohio, 17 species being common to both areas. This fauna of central Ohio is so much more abundant than those north and south of it that Stauffer says it is difficult to prove they are the same shale, although he believes them to be the same.

__________ 1938a, The fauna of the typical Olentangy shale: Jour. Geology, v. 46, p. 1075-1078.

Megascopic and microscopic fossils found in the Olentangy confirm the assignment of the Olentangy shale to the Middle Devonian. Faunal list.

__________ 1939, Middle Devonian <u>Polychaeta</u> from the Lake Erie district: Jour. Paleontology, v. 13, p. 500-511.

Describes trails and burrows observed in the shale or limestone lenses (of the Middle Devonian Olentangy shale of Ontario).

__________ 1944, The Geological section at the limestone mine, Barberton, Ohio: Am. Jour. Sci., v. 242, p. 251-271, 1 pl., 1 fig. incl. index map.

Several disconformities and other indications of interrupted sedimentation are evident in the shales. The Berea is missing, so that the Sunbury shale rests on the Bradford shale. Notes the presence of the Hamilton (Olentangy) shale.

Stauffer, C. R., Hubbard, G. D., and Bownocker, J. A., 1911, Geology of the Columbus quadrangle: Ohio Geol. Survey Bull. 14, 133 p.
Considers stratigraphy and paleontology of the shale series.

Stensio, E. A., 1925, On the head of the Macropitalichthyids with certain remarks on the head of the other arthrodires: Field Mus. Nat. Hist., Geol. Ser., no. 4, p. 89-198, pls. 19-31, 26 figs.

________ 1937, Notes on the endocranium of a Devonian Cladodus: Upsala Bull. Geol., v. 27, p. 128.
Describes and figures Cladodus wildungensis.

Stephens, J. G., 1953, A preliminary study of the basal sandy zone of the Ohio-New Albany black shale: Univ. Cincinnati, M. S. thesis, (unpub.).

Stewart, G. A., 1927, Fauna of the Silica shale of Lucas County: Ohio Geol. Survey Bull. 32, 76 p., 5 pls., 1 map.
Traverse formation in northwestern Ohio considered as an approximate time equivalent of Delaware limestone to Olentangy shale of central Ohio, and 53 percent Traverse fossils have been identified with Delaware and Olentangy species. The Olentangy has been recognized as the only true representation of Hamilton in central Ohio, apart fromthe Prout limestone, which lies above Olentangy in the Sandusky region. Names the Silica "shale beds" now known as the Silica formation. Microfossils of Silica shale and Olentangy shale show strong resemblance. The author compares the Silica and Plum Brook faunas and notes that they differ greatly in their main elements. He suggests that the Silica shale may be the westward equivalent of the Prout limestone.

________ 1930, Additional species from the Silica shale of Lucas County, Ohio: Ohio Jour. Sci., v. 30, p. 52-58.
Includes systematic consideration of eight species found after publication of the previous faunal list of the Silica shale (Stewart, 1927).

________ 1936, Ostracodes of Silica shale, Middle Devonian of Ohio: Jour. Paleontology, v. 10, p. 739-763.
Systematic consideration of the Ostracode fauna of the Silica shale.

________ 1938, The Middle Devonian corals of Ohio: Geol. Soc. America Spec. Paper 8, 120 p.
Describes all previously reported corals from the Prout and Plum Brook formations plus some new species. Central Ohio Olentangy shale is correlated with the Silica shale of northwestern Ohio and may be the equivalent of the Olentangy shale of north-central Ohio. The Ten Mile Creek dolomite of northwestern Ohio may be equivalent to the Prout (Widder beds) limestone of north-central Ohio. Of the 100 species included in the faunal summary and stratigraphic distribution, 6 species are found in the Delaware limestone, 7 in the Olentangy shale, 12 in the Prout limestone, 18 in the Ten Mile Creek dolomite, and 8 in the Silica shale.

________ 1955, Age relations of Middle Devonian limestone in Ohio: Ohio Jour. Sci., v. 55, p. 147-181.
Considers the stratigraphic and faunal relationships of the Middle Devonian limestone formations of Ohio (east and west of the Cincinnati arch) and their correlation with the New York type section.

Stewart, G. A., and Hendrix, W. E., 1939, Ostracodes as a possible aid in the Olentangy

shale problem: (abs.), Geol. Soc. America Bull., v. 50, p. 1988-1989.
Sixteen localities in central and northern Ohio yielded an ostracode fauna of 53 species. A comparative study of the faunas from the two areas shows that there is little resemblance between them. The northern fauna appears to be a typical Hamilton assemblage and has many species in common with the Silica shale, Traverse of Michigan, and Hamilton of Ontario. Central Ohio region lacks typical Hamilton species.

Stewart, G. A., and Hendrix, W. E., 1945, Ostracoda of the Plum Brook shale, Erie County, Ohio: Jour. Paleontology, v. 19, p. 87-95, 1 pl.
Systematic consideration of the Ostracoda fauna of the Plum Brook shale. These authors cannot accept the equivalence of the Plum Brook and Olentangy shale. The ostracoda of these two shales bear little resemblance to one another.

__________ 1945a, Ostracoda of the Olentangy shale, Franklin and Delaware Counties, Ohio: Jour. Paleontology, v. 19, p. 96-115, 2 pls.
Systematic treatise on the Ostracoda fauna of the Olentangy shale. Summarizes opinions of various authorities pertinent to the stratigraphic and faunal relations of the shale. The authors say the ostracoda fauna suggests a Late Devonian age.

Stockdale, P. B., 1939, Lower Mississippian rocks of the east-central interior: Geol. Soc. America Spec. Paper 22, 248 p.
Considers the shale series of Ohio and discusses the black shale problems. His consideration of the Ohio formations is based upon a search of literature rather than extensive fieldwork as was performed in Indiana and Kentucky.

__________ 1948, Some problems in Mississippian stratigraphy of the southern Appalachians, in Weller, J. M., ed., Symposium on problems of Mississippian stratigraphy and correlation: Jour. Geology, v. 56, p. 264-268; (abs.) Geol. Soc. America Bull., v. 58, p. 1278, (1947).
Discusses the "Black shale problem" as it applies to Ohio and other states.

Stout, Wilber, 1916, Geology of southern Ohio; including Jackson and Lawrence Counties and parts of Pike, Scioto, and Gallia: Ohio Geol. Survey Bull. 20, 723 p.
Considers the Bedford shale for each county, particularly its oil and gas potentials.

__________ 1932, Ohio's progress due largely to State's abundant mineral resources: Pit and Quarry, v. 23, no. 11, p. 31-32.
Discusses stratigraphy and economic use of the Olentangy shale, Ohio formation, and Bedford formation.

__________ 1945, The iron ore bearing formations of Ohio: Ohio Geol. Survey Bull. 45, p. 14-15.
Discusses the ferruginous concretions in the Ohio shale.

Stout, Wilber, and Lamborn, R. E., 1924, Geology of Columbiana County: Ohio Geol. Survey Bull 28, 408 p.
Considers the oil and gas possibilities of the Devonian-Mississippian series.

Stout, Wilber, and others, 1935, Natural gas in central and eastern Ohio, in Geology of natural gas: Tulsa, Okla., Am. Assoc. Petroleum Geologists, p. 897-914, 3 figs, maps.

Stout, Wilber, Ver Steeg, Karl, and Lamb, G. F., 1943, Geology of water in Ohio: Ohio Geol. Survey Bull. 44, 694 p.
Stratigraphic and water potentials of the Devonian-Mississippian shales.

Strom, K. M., 1936, Land-locked waters: Det norske videnskapp-Akademi i Oslo, Nat. Naturv. Klasse, v. 1, no. 7, p. 1-85.

Circulation of the bottom water would be prevented or impeded in landlocked waters only if there were a submerged or exposed barrier near the threshold of an embayment. Deposition takes place in barred or landlocked basins under conditions that do not permit circulation of bottom waters, thus depriving the water of oxygen and causing the bottoms to have an absence of benthonic life. The landlocked basins described are bays and fjords with narrow connections with the sea and an elevated bottom at the threshold, so that the basins are deeper inside than at the entrance.

Stugard, Frederick, Jr., Wyant, D. G., Gude, A. J., 3rd, 1951, Secondary uranium deposits in the United States: (abs.), Geol. Soc. America Bull., v. 62, p. 1542.

Reconstituted (or secondary) uranium mineral formed in domestic deposits includes oxides, phosphates, silicates, vanadates, arsenates, sulphates, and carbonates. Next to the vanadates carnotite and tyuyamunite, the most abundant are the phosphates autumite and torbernite and the silicate uranophane. Less common are deposits containing the oxides gummite and pitchblende. Most secondary uranium deposits show no apparent relationship to known primary uranium minerals. Many uranium compounds appear to be highly soluble and mobile. Successful distinction between secondary deposits resulting from concentration and those resulting from dispersion of primary deposits has not been made to date.

Stumm, E. C., 1941, The fauna and stratigraphic relationships of the Prout limestone and Plum Brook shale of northern Ohio: (abs.) Ohio Jour. Sci., v. 41, p. 415.

Correlates the Prout limestone with the Centerfield limestone of the New York Hamilton. The underlying Plum Brook shale is correlated with the Skaneatles shale.

__________ 1942, Fauna and stratigraphic relations of the Prout limestone and Plum Brook shale of northern Ohio: Jour. Paleontology, v. 16, p. 549-563.

Recognizes a disconformity between the Prout and Huron shale, as all the upper Ludlowville and the entire Moscow are absent in northern Ohio. Gives faunal lists, correlations, and summary of previous work.

__________ 1956, A revision of A. W. Grabau's species of Mucrospirifer from the Middle Devonian Traverse group of Michigan: Michigan Univ. Mus. Paleontology Contr., v. 13, p. 81-94, 1 fig., 3 pls.

Considers formations of Michigan that correlate with the Silica shale and Ten Mile Creek dolomite of Ohio.

Stumm, E. C., Kellum, L. B., and Wright, J. D., 1956, Devonian strata of the London-Sarnia area, southwestern Ontario, Canada; Field trip Michigan Geological Society: Michigan Geol. Survey, 21 p.

Relationships of the Devonian shale pertinent to the Devonian-Mississippian shale sequence in Ohio.

Summer, F. B., 1908, An intensive study of the flora and fauna of a restricted area of sea bottom: U. S. Bur. Fisheries Bull, v. 28, p. 1225-1263.

According to Summer the physical texture of the bottom materials is "foremost among the conditions determining the distribution of the bottom-dwelling organisms."

Swartz, J. H., 1923, The age and stratigraphy of the Chattanooga shale in northeastern Tennessee and in Virginia: Am. Jour. Sci. (5), v. 17, p. 431-438.

Swartz divides the Chattanooga shale into three distinct members: Big Stone Gap (upper member), Olinger, and Cumberland Gap (lower member) with the upper two members being Mississippian in age on the faunal basis that Chonetes geniculateus was abundant in the Olinger member.

Swartz, J. H., 1929, The Devonian-Mississippian boundary in southeastern United States: Science, v. 70, p. 609.
Discusses the problem of the probable age of the black shales.

Tarbell, Eleanor, 1941, Antrim-Ellsworth-Coldwater shale formations in Michigan: Am. Assoc. Petroleum Geologists Bull., v. 25, p. 724-733.
Probable manner of the development of typical Paleozoic shales.

Tarr, W. A., 1927, Alternating deposition of pyrite, marcasite, and possibly melnikovite: Am. Mineralogist, v. 12, p. 417-421.
Strongly acid waters lead to the formation of marcasite; slightly acid (or neutral) precipitate pyrite; and alkaline waters precipitate melnikovite.

Trask, P. D., 1925, The origin of the Mansfeld Kupferschiefer shale, Germany; A review of the current literature: Econ. Geology, v. 20, p. 746-761.
Similarities seem to exist between the Ohio shale and the Kupferschiefer of Germany.

________ 1932, Origin and environment of source of petroleum: Houston, Texas, Gulf Publishing Co., 373 p.
Trask observes that organic content of recent sediments increases in the smaller size fractions.

________ 1935, Relation of salinity to the calcium carbonate content of marine sediments: U. S. Geol. Survey Prof. Paper 186-N, p. 273-299, 1 pl. map, 8 figs. incl. map.

________ (ed.) 1939, Recent marine sediments; a symposium: Tulsa, Okla., Am. Assoc. Petroleum Geologists: 736 p., illus.
A symposium on recent marine sediments which presents papers by specialists in various fields. Covers such subjects as transportation of sediment, relationship of oceanography to sedimentation, deposits associated with the strand line, near-shore sediments, pelagic deposits, special features of sediments, and methods of study, mechanical analysis, organic content, graphic representation, statistical analysis, mineral analysis, X-ray methods, and bottom-sampling apparatus.

Twenhofel, W. H., 1932, Treatise on sedimentation: Baltimore, Md., Williams and Wilkins Co., 914 p.
Discusses sources, production, transportation, structure, deposition, diagenesis, lithification, and environments of sediments.

________ 1939, Environments of origin of black shales: Am. Assoc. Petroleum Geologists Bull., v. 23, p. 1178-1198; (abs.) Oil Weekly, v. 93, no. 3, p. 69, 1939.

Ulrich, E. O., 1888, A list of the Bryozoa of the Waverly group in Ohio with descriptions of new species: Denison Univ., Bull. Sci. Lab., v. 4, p. 63-96, 2 pls.
Systematic paper of the Bryozoa found in (especially) the Cuyahoga shale. None was specifically noted for the Bedford shale.

________ 1890, New and little known American Paleozoic ostracoda: Cincinnati Soc. Nat. Hist. Jour., v. 13, no. 3, p. 104-137, 173-211.

________ 1911, Revision of the Paleozoic systems: Geol. Soc. America Bull., v. 22, p. 625-668, pl. 25-29.
The middle Tennessee Chattanooga shale is imperfectly equivalent to the Cleveland shale, Bedford shale, Berea sandstone, and Sunbury shale of Ohio.

Regards the Chagrin as a formation and places it stratigraphically beneath the Huron shale. The Huron and Cleveland shales overlap the light-colored Chagrin shale instead of including it between them. This interpretation is based on the belief that the fish Dinichthys herzeri is Waverly in age and that the Devonian shale (Chagrin shale) would naturally have to underlie the Mississippian shale (Huron shale). Actually, Ulrich says, the Cleveland and Huron overlap the Chagrin.

Ulrich, E. O., 1915, Kinderhookian age of the Chattanoogan series: Geol. Soc. America Bull., v. 26, p. 96-99.
Gives eleven points explaining why Ulrich believed that the black shales of Ohio were younger than he had thought they were in 1912.

Ulrich, E. O., and Schuchert, Charles, 1902, Paleozoic seas and barriers in eastern North America: New York State Mus. Bull. 52, p. 633-663, map.
Barriers in Ohio are the Helderbergain barrier on the east and the Cincinnati axis on the west.

Ulrich, E. O., and Smith, W. S. T., 1905, The lead, zinc, and fluorspar deposits of western Kentucky: U. S. Geol. Survey Prof. Paper 36, 218 p., 15 pls.
The authors refer to the Ohio shale as Devonian and separate it from the Mississippian by an unconformity. Ulrich, (1911, p. 307 and pl. 2) puts it in the Carboniferous.

Ulrich, E. O., and Bassler, R. S., 1926, A classification of the toothlike fossils, conodonts, with descriptions of American Devonian and Mississippian species: U. S. Natl. Mus. Proc., v. 68, p. 1-63.
Discusses the probable age of the black shale. Notes that none of the New York Genesee and Portage conodont species were identical with species found in the Ohio shale. Authors regard this as conclusive evidence of the post-Devonian age of these formations.

U. S. Department of Agriculture, 1950, Annotated bibliography on sedimentation: Compiled under auspices of subcommittee on sedimentation, Federal Inter-Agency River Basin Committee. Prepared under the supervision of the Soil Conserv. Service, Dept. of Agriculture.

Urry, W. D., 1948, Radioactivity of ocean sediments; VII, rate of deposition of deep-sea sediments: Jour. Marine Research (Sears Foundation), v. 7, p. 618-634.
The rate of sedimentation can be determined from Ra content of the sediments, since variation in Ra content occurred during the establishment of radioactive equilibrium in deep-sea deposits. Rates of deposition as a function of time (for the past half million years) are reported for red clay, globigerina ooze, foraminifera marl, glacial marine deposits, and calcareous blue mud.

Van Horn, F. R., and Van Horn, K. R., 1933, X-ray study of pyrite or marcasite concretions in the rocks of the Cleveland, Ohio quadrangle: Am. Mineralogist, v. 8, p. 288-294, 2 figs.
The results of crystallographic observations and x-ray analyses show that no marcasite has been found, as yet, in the iron sulfide concretions in the Chagrin, Cleveland, and Bedford shales of the Cleveland district. However, the Olentangy shale at Delaware, Ohio, does contain marcasite.

Van Pelt, H. L., 1933, Some ostracodes from the Bell shale, Middle Devonian of Michigan: Jour. Paleontology, v. 7, p. 325-342.
Lists some ostracodes common to the Plum Brook shale.

Ver Wiebe, W. A., 1916, The Berea formation of Ohio and Pennsylvania: Am. Jour. Sci. (4), v. 42, p. 43-58; (abs.) Science, v. 43, p. 395.

The Cussewago sandstone thins out and disappears from the section about longitude 80°5' W. In Pennsylvania the Berea is represented by the Corry and Cussewago formations of White.

Ver Wiebe, W. A., 1917, Correlation of the Devonian shales of Ohio and Pennsylvania: Am. Jour. Sci. (4), v. 44, p. 33-47.
Reconnaissance literature survey correlating the rocks of Ohio and Pennsylvania. Concludes from faunal evidence that the Bedford shale was Devonian in age in northeastern Ohio. Actually, conclusions are based primarily on lithologic field studies of the formations. Regards the Bedford as Bradfordian in age

________ 1917a, Correlation of Mississippian of Ohio and Pennsylvania: Am. Jour. Sci. (4), v. 43, p. 301-318.
Explanation of change in strand line and transgression. Though clear-cut conclusion from available evidence is wanting, author places Berea as base of Mississippian.

________ 1918, The Devono-Carboniferous boundary rocks of Ohio, Pennsylvania, and New York: Cornell Univ., Ph. D. dissert., (unpub.).

Ward, L. F., 1889, The geographical distribution of fossil plants: U. S. Geol. Survey 8th Ann. Rept., pt. 2, p. 884-891.
Summation of plants in the black shale of Ohio.

Warthin, A. S., Jr., 1934, Common ostracoda from the Traverse group: Michigan Univ., Contrib. Mus. Paleontology, v. 4, p. 205-226.

________ 1937, Beyrichiacea, in Type invertebrate fossils of North America (Devonian): Wagner Tree Inst., unit 9-A, 106 cards, figs.

Weirich, T. E., 1940, Comparative geology of the Cincinnati arch: (abs.) Tulsa Geol. Soc. Digest, Jan. 1939-March 1940, p. 29-30.

Weller, J. M., and Workman, L. E., 1948, Structural development of the eastern interior basin: (abs.), Am. Assoc. Petroleum Geologists Bull., v. 32, p. 300.
Silurian rocks deposited in the basin provide little evidence of importance dealing with structural changes. Slow subsidence occurred during Mississippian time.

Weller, J. M., and others, 1948, Correlation of the Mississippian formations of North America: Geol. Soc. America Bull., v. 59, p. 91-196.

Weller, Stuart, 1895, A circum-insular Paleozoic fauna: Jour. Geology, v. 3, p. 903-917, illus.
Describes and illustrates the distribution of land and water in the United States during the Devonian time.

________ 1909, Correlation of the Middle and Upper Devonian and Mississippian faunas of North America: Jour. Geology, v. 17, p. 257-285.
The faunas of the Upper Devonian of the eastern continental province were local in their development. The the early part of Lake Devonian time the sea retreated northward from its greatest southward areal extension during Hamilton time, and later transgressed toward the south and southwest; this retreat and readvance was recorded in the unconformity at the base of the Upper Devonian black shale.

Wells, J. W., 1939, Association of crinoids with Callixylon in the lower Ohio shale: Paleobiologica, v. 7, p. 105-110, 2 figs.

"A large fossil trunk of the Upper Devonian cordaitean tree, Callixylon newberryi, in the Ohio State University Geological Museum, from the lower Ohio shale of Delaware County, Ohio, is particularly interesting because of associated crinoid stems of the genus Melocrinus. Crinoids are not known to occur in the black Ohio shale and this association suggests some sort of attachment of the crinoids or their stems to the log while it was floating, and may afford some data on the paleogeography of the areas of black shale deposition."

Wells, J. W., 1947, Provisional paleoecological analysis of the Devonian rocks of the Columbus region: Ohio Jour. Sci., v. 47, p. 119-126.
Dark-shale lithotope and light-shale lithotope are described, which refer specifically to the Ohio shale and Olentangy shale, respectively.

Wenberg, E. H., 1938, The Paleozoic stratigraphy of Lorain County, Ohio: Oberlin College, A. M. thesis, (unpub.).

Westgate, L. C., 1926, Geology of Delaware County: Ohio Geol. Survey Bull. 30, 147 p.
Discusses stratigraphy, structural features, paleontology, sedimentation, geologic history, and ceramic uses of the Devonian-Mississippian shale sequence.

White, David, 1909, The Upper Paleozoic flora, their succession and range: Jour. Geology, v. 17, p. 320-341.
Upper Devonian flora shows little evidence of climatic contrast with the Middle Devonian flora, which is noted for its high degree of unity in the northern hemisphere. White notes the wide extent and near identity of the flora from Pennsylvania to southern Europe and Australia.

__________ 1911, Value of floral evidence in marine strata as indicative of nearness of shores, in Conference on faunal criteria in Paleozoic paleogeography: Geol. Soc. America Bull., v. 22, p. 221-227.
White suggests that the areas of most abundant terrigenous muds with plant ingredients, between Central America and the Cocos or Galapagos Islands, are regions of deposition of somewhat carbonaceous shales, probably calcareous in certain districts, and possibly comparable to those of the Upper Devonian in portions of Ohio.

__________ 1926, General features of the Mississippian flora of the Appalachian trough: West Virginia Geol. Survey County Reports, Mercer, Monroe, and Summers Counties, p. 837-843.

White, David, and Stadnichenko, T., 1923, Some mother plants of petroleum in the Devonian black shales: Econ. Geology, v. 18, p. 238-253, pl. 5-9.
Considers the microscopic plant material of the Ohio shale.

White, I. C., 1881, Middle Devonian rock: Pennsylvania Geol. Survey, (2nd), Rept. Prog. QQQQ, p. 1-355.
Names the Gerard shale for a mass of Devonian shales in Erie County, Pa., which is equivalent to only a portion of Newberry's Erie shale. Correlates the Cussewago strata with Bedford shale of eastern Cuyahoga County, Ohio.

Whitfield, R. P., 1880, Notice of the occurrence of rock representing the Marcellus shale of New York in central Ohio: Am. Assoc. Adv. Sci. Proc., v. 28, p. 297-299.

Whitfield, R. P., and Hall, J., 1873, Notice of three new species of fossil shells from the Devonian of Ohio: New York State Mus. 23rd Ann. Rept., p. 240-241.

Whittlesey, Charles, 1849, Outline sketch of the geology of Ohio, in Howe, Henry, Historical collections of Ohio; Cincinnati, p. 577-589, map; reproduced with map, Cleveland, 1856.

"A person travelling from the west line of Adams County eastward to the Little Scioto, in Scioto County, would pass over the outcropping edges of all these rocks (Ordovician limestone to coal massives) and would see all the formation of Ohio."

Whittlesey, Charles, 1869, Red shale; Waverly flags; Black shale, in Contributions to the geology of Ohio: Cleveland, Ohio, Fairbanks, Benedict and Co., p. 41-43.
Says in describing his Devonian system, "It is not practicable, with our present knowledge, to divide the Carboniferous shales of Ohio into formations. Yet in New York they are described under the names of Genesee and Hamilton series, of the Devonian or old red sandstone system. In Ohio the upper part is frequently more sandstone than shale, and is known as the Waverly series. Professor Winchell... concludes that from the black shales upward, the Carboniferous predominates over the Devonian." Whittlesey prefers, as these units are not separable into formations, to call this portion of the Devonian as follows: Third, Red Shale (Bedford); Fourth, Waverly flagstone (Bedford), Fifth, Black shale.

__________ 1871, Geological Survey of Ohio; Examination by the Retrenchment Committee of the House of Representatives, with the reply of Col. Chas. Whittlesey: Columbus, Ohio, Ohio State Jour. Book and Jobs Rooms, 4 p.
"It is this belt, occupied by the so-called Devonian shales and sandstones, that are the principal sources of petroleum, or stone oil."

__________ 1878, General geology of the counties of Columbiana, Stark, and Tuscarawas (Ohio): Cleveland, Ohio, private pub.
The "Waverly group" embraces the flags and shales below the Berea grit to the black or "Huron shale." Author places the Berea grit in the "Conglomerate group."

Wickwire, G. T., 1936, Crinoid stems on fossil wood: Am. Jour. Sci. (5), v. 32, p. 145-146, 1 fig.
This paper describes an unusual occurrence of crinoid stems embedded in fossil wood found in the New Albany black shale (Devonian) near Lexington, Ind. Suggests that there must have been some surface movement of the water. The crinoid stems are orientated in one direction, lengthwise on the log.

Willard, Bradford, Swarz, F. M., and Cleaves, A. B., 1939, The Devonian of Pennsylvania; Middle and Upper Devonian: Pennsylvania Topog. and Geol. Survey (4th)Bull. G-19, 481 p.
Gives a brief summary of correlations of the Devonian and Mississippian of Ohio and Pennsylvania.

__________ 1946, Continental-marine Mississippian relations in northern Pennsylvania: Geol. Soc. America Bull., v. 57, p. 781-796.
Considers rocks of Pennsylvania allied to those of Ohio.

Williams, A. B., 1940, Geology of the Cleveland region: Cleveland Mus. Nat. Hist., Geol., ser. 1, Pocket Nat. Hist. no. 9, 59 p.
Describes the lithologic characteristics and fauna of the Devonian-Mississippian shale series and gives loaclities where they can be observed. Cleveland Mus. Nat. Hist. specimens no. 5912 (Cladoselache) and no. 5768 (head of a Dinicthys) are excellently illustrated as figs. 12 and 13, respectively.

Williams, H. S., 1888, Report of the sub-committee on the Upper Paleozoic (Devonic): Am. Geologist, v. 2, p. 225-247.
Describes and correlates the Devonian shales of Ohio. Ohio is placed in the "Eastern Continental Area" of the North American Devonian areas. Discusses the problems of determining the top of the Devonian in Ohio.

Williams, H. S., 1895, On the recurrence of Devonian fossils in strata of Carboniferous age: Am. Jour. Sci. (3), v. 49, p. 94-101.
Reviews the fossils common to the Devonian black shales and the Lower Mississippian formations of the United States.

_________ 1897, On the southern Devonian formations: Am. Jour. Sci. (4), v. 3, p. 393-403, map; (abs.) Science, (new series) v. 5, p. 92-93.
Reports Carboniferous fossils in the topmost beds of the Chattanooga shale at Irvine. Previous to this report the Chattanooga had been considered gener ally of Genesee age.

_________ 1903, The correlation of geological faunas, a contribution to Devonian paleontology: U. S. Geol. Survey Bull. 210, 147 p., 1 pl.
The Olentangy (or Hamilton here called) marks the top of pure Hamilton fauna; top of Cleveland shale marks lower limit of Chemung fauna; top of Bedford marks lower limits of Waverly fauna.

Williams, H. S., and Kindle, E. M., 1905, Contributions to the Devonian paleontology, 1903: U. S. Geol. Survey Bull. 244, p. 20-21.
On the east side of the Cincinnati arch the black shale is in an unconformable relation with the underlying rock; west of the arch a limestone sometimes occurs conformably below the black shale, and where this limestone occurs the unconformity appears below this limestone.

Williams, M. Y., 1917, The Ohio shales of southwestern Ontario: Canada Geol. Survey, Summary Rept. 1917, pt. E, p. 26-28.

Willis, B., 1909, Paleogeographic maps, North America; 5, Middle Devonian, North America; 6, Mississippian, North America: Jour. Geology, v. 17, p. 286-288.
The time represented by the Devonian map is that before and after the invasion of the Hamilton fauna into the New York embayment. Most of Ohio was covered by an epicontinental sea; the extreme south-central part was temporary land (Greenfield outcrop area). The Mississippian map is quite similar to that of the Devonian of Ohio, except the Mississippian land area has migrated westward and covers a greater positive area.

Wilmarth, M. G., 1938, Lexicon of geologic names of the United States: U. S. Geol. Survey Bull. 896, 2396 p.

Winchell, N. H., 1874, The geology of Delaware County, in Ohio Geol. Survey, Vol. 2, pt. 1, p. 272-313.

Winchester, D. E., 1918, Results of dry distillation of miscellaneous shale samples: U. S. Geol. Survey Bull. 691-B, p. 52.
Reports the results of distillation of Ohio (Chattanooga) shale (Devonian) from a road-metal quarry at Irvine, Estill County, Ky. This sample assayed 7 gallons per ton.

Winslow, J. D., White, G. W., and Webber, E. E., 1953, The water resources of Cuyahoga County, Ohio: Ohio Div. Water Bull. 26, 123 p.
Considers base of Bedford shale the base of Mississippian.

Winslow, Marcia, 1954, Plant microfossils from Upper Devonian and Lower Mississippian rocks of Ohio: Ohio State Univ., Master's thesis, (unpub.).
Reports an investigation of spores and other microfossils found in the Chagrin, Cleveland, and Bedford shale samples collected from six localities in northern Ohio. The plant microfossils include a multitude of types having great botanical disparity, which for the most part represent a highly varied assemblage of Upper Devonian and Lower Mississippian land plants. Base of the Mississippian system is placed at the bottom of the Bedford shale. The Chagrin and Cleveland shales are regarded as uppermost Devonian in age.

APPENDIX – SYSTEMATIC PALEONTOLOGIC CHART

The following chart is an uncorrected list of fauna and flora found in the Devonian-Mississippian shale sequence of Ohio.

Symbols and abbreviations used in the chart are defined as follows:

X - Fossils identified in only one stratigraphic unit.

O - Fossils identified in more than one stratigraphic unit.

? - Fossils identified tentatively.

ls. - limestone

sh. - shale

dol. - dolomite

ss. - sandstone

Ohio shale, north - area of Ohio in which the Ohio shale is discernible as the Huron, Chagrin, and Cleveland units.

Ohio shale, south - area of Ohio in which the Ohio shale is not discernible as smaller units.

	Dundee ls.	Delaware ls.	Silica sh.	Ten Mile Creek dol.	Plum Brook sh.	Prout ls.	Olentangy sh.	Huron sh.	Chagrin sh.	Cleveland sh.	Bedford sh.	Berea ss.	Ohio sh.	
													South	North
PHYLUM COELENTERATA														
Class Stromatoporoidea														
Coenostroma pustulifera						X								
Stromatopora granulata Nicholas	X													
Class Anthozoa (Corals)														
Acrophyllum sp. Stumm						X								
Alveolites goldfussi Billings						X								
A. monroei Cleveland					O		O							
Amplexus hamiltonae Hall						X								
Aulacophyllum hemicrassatum Sloss						X								
Aulopora sp. Stewart				X										
A. coaptus Stewart		X												
A. conuta					X									
A. serpens Goldfuss	O	O	O	O	O	?	O							
Baryphyllum verneuilarnum						X								
Blothrophyllum cinctutum Davis					O	O								
B. conatum (Hall)						X								
Ceratopora auloporoidea (Davis)					X									
C. flabellata Greene			O		O		O							
C. intermedia (Nicholson)						X								
C. jacksoni Grabau		O	O											
C. nobilis (Billings)						X								
C. rugosa					X									
C. westgatensis Stewart		X												
Cladopora canadensis Rominger	O			O		O								
C. fisheri (Billings)						X								
C. frondosa (Billings) Nicholson				O		O								
C. lucasensis Stewart	X													
C. roemeri (Billings)	O					O								
Cyathophyllum robustum Hall			X											
Cylindrophyllum panicum				X										
Cystiphyllum sp. Stumm						X								
C. americanum Edwards and Haimes	X													
C. vesiculosum Goldfuss	O	O	O	O		O								
Diphyphyllum panicum Winchell	X													
Emmonsia arbuscula (Hall)	O					O								
E. radiciformis (Rominger)	O					O								
Eridophyllum archiaci (Billings)						X								
E. seriale Edwards and Haime						X								
E. subcaespitosum (Nichólson)						X								
Favosites alpenaensis Winchell			O			O								
F. arbuscula Hall				?										
F. argus Hall						X								
F. billingsi						X								
F. hamiltonae Hall				X										
F. hemispherica (Troost)	O			O		O								
F. limitaris Rominger	O			O										
F. nitella Winchell	O		O	O		O								
F. placenta Rominger	O				O	O	O							
F. radiciformis Rominger						X								
F. turbinatus Billings		O				O								
Hadrophyllum d'orbignyi Edward and Haime		X												

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PHYLUM COELENTERATA (con.)														
Class Anthozoa (con.)														
Heliophyllum sp. Stumm						X								
H. arachne Hall						X								
H. confluens Hall						X								
H. degener Hall						X								
H. halli Milne-Edward and Hall	O	O	O	O		O								
H. proliferum Nicholson				X										
H. reflexum Hall						X								
H. scyphus Rominger						X								
Heterophrentis sp.			X											
H. prolifica (Billings)		O	O	O	O	O	O							
H. simplex (Hall)			O	O		O								
Hexagonaria anna (Whitfield)			X											
H. tabulata Stumm			X											
Lopholasma delawarensis Baker							X							
Prismatophyllum annum (Whitfield)	O			O										
P. truncata Stewart	X													
P. whitfield Stewart	X													
Michelinia dividua (Hall)							X							
Romingeria cornuta (Billings)					O		O							
R. julia (Winchell) ?											X			
R. unbellifera (Billings)				X										
Stereolasma rectum (Hall)						X								
Streptelasma sp.							X							
S. ungula Hall	X													
Striatopora sp. Stumm						X								
Strombodes alpinensis Rominger				X										
Syringopora sp.			O			O	O							
S. intermedia Nicholson						X								
S. perelegans Billings	O				O		O							
Tortophyllum cysticum (Winchell)						X								
Trachypora elegantula (Billings)				O		O								
T. limbata (Eaton)						X								
Zaphrentis prolifica Billings			O		O	O	O							
Z. simplex Hall	O		O											
Class Scyphozoa														
Conularia sp.										X				
C. micronema Meek											O	O		
C. Newberryi Hall											O	O		
PHYLUM ECHINODERMA														
Subphylum Pelmatozoa														
Class Blastoidea														
Blastoid species			X											
Class Crinoidea														
Actinocrinus daphni											X			
A. eris											X			
A. helice											X			
A. viminalis											X			
Ancyrocrinus sp. Newberry						X								
Arthroacantha sp. Stumm						X								
A. carpenteri (Hinde)			X											

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													South	North
PHYLUM ECHINODERMA (con.)														
Class Crinoidea (con.)														
Crinoid stems			X											
Dolatocrinus sp. Stumm						X								
Euryocrinus laddi			X											
E. (?) laddi Stewart			X											
Forbesiocrinus communis											X			
F. kelloggi											X			
F. tardus											X			
Gilbertsocrinus ohioensis Stewart			X											
Hexacrinus (?) sp.			X											
Megistrocrinus depressus Hall						X								
M. ontario Hall							X							
M. rugosus Lyon and Cassidy							X							
M. spinulosis (?) Lyon	X													
Melocrinus bainbridgensis Hall and Whitfield								X						
M. (Ctenocrinus) bainbridgensis Hall and Whitfield								X					O	
M. clarkei (Hall) Williams							X							
Platycrinus bedfordensis Hall and Whitfield										X				O
P. contritus											X			
P. graphicus											X			
P. richfieldensis Hall and Whitfield											X			
Poteriocrinus (Scaphiocrinus?) corycia											X			
P. crineus											X			
P. Scaphiocrinus (Poteriocrinus) aegina											X			
P. Scaphiocrinus (Poteriocrinus) lyriope											X			
P. Scaphiocrinus subcrinus											X			
P. Scaphiocrinus subtortuosus											X			
Zeacrinus merope											X			
Z. paternus											X			
PHYLUM ANNELIDA (ANNULATA)														
Class Chaetopoda														
Spirorbis angulatus					X									
S. arkonensis Nicholson			X											
S. omphalodes					X									
S. planum			X											
Class Sipunculoidea														
Arenicolites cf. duplex Williams									X					
CONODONTS														
Acodus formosus Stauffer			X											
A. inopinatus Stauffer			O				O							
A. zionensis Stauffer							O							
Ancyrodella sp. Miller and Youngquist							X							
A. buckeyensis Stauffer							X							
A. plena Stauffer							X							
A. robusta Stauffer							X							
Ancyrognathus sp. Hass								X					O	
A. sp. Stauffer							X							
A. asteroideus Stauffer							X							
A. bifurcata (Ulrich and Bassler)								X					O	
A. euglypheus Stauffer							X							
A. irregularis Branson and Mehl								X					O	

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CONODONTS (con.)														
Bryantodus sp. Stauffer							X							
B. amalitus Stauffer							X							
B. andersonensis Stauffer							X							
B. argutus Stauffer							X							
B. ausablensis Stauffer							X							
B. bellatulus Stauffer							X							
B. bennerensis Stauffer					X									
B. (?) bezoensis Stauffer							X							
B. bryanti Stauffer							X							
B. commutatus Huddle								X					O	
B. concavus Huddle							O	O					O	
B. dignatus Stauffer							X							
B. equalis Cooper								X					O	
B. eriensis Stauffer							X							
B. germanus Holmes								X					O	
B. grahami Stauffer							X							
B. humboltensis Stauffer					O		O							
B. ignotus Stauffer			X											
B. impariles Stauffer							X							
B. inclinatus Holmes								X					O	
B. inequalis Holmes								X					O	
B. longicollis (Huddle) Bond								X					O	
B. minutus Ulrich and Bassler								O		O			O	
B. nitidus Ulrich and Bassler								X					O	
B. nobilis Stauffer							X							
B. olentangiensis Stauffer							X							
B. parvus Huddle								X						
B. prosseri Stauffer							X							
B. radiatus (Hinde)								X					O	
B. sciotoensis Stauffer							X							
B. serrulus Huddle								X					O	
B. stratfordensis					O		O							
B. subcarinatus Huddle								X					O	
B. subequalis Cooper								X					O	
B. sublimatus Stauffer							X							
B. subplanus Huddle								X					O	
B. trigonalidentus Bond								X					O	
B. wesleyianensis Stauffer							X							
B. winchelli Stauffer							X							
Cervicornoides alternatus Stauffer			O		O		O							
Ctenognathus deparcus Stauffer							X							
C. elegans Stauffer							X							
C. falcatus Stauffer							X							
C. falsiformis Stauffer							X							
C. firmus Stauffer							X							
Cyrtoniodus (?) delicatus Stauffer							X							
C. worthingtonensis Stauffer							X							
Distacodidea, 3 sp. Bond								X					O	
Distacodus rectus, Ulrich and Bassler								O		O			O	
Euprioniodina sp. Hass								X						O
E. sp. a Stauffer							X							

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CONODONTS (con.)														
E. sp. b. Stauffer							X							
E. sp. Stauffer					O		O							
E. dora Stauffer							X							
E. prona Huddle								X					O	
Falcodus sp. Stauffer							X							
F. incultus Stauffer							X							
Gyrognathus carinatus							X							
Hibbardella ? sp. Stauffer							X							
H. angulata (Hinde)								X					O	
Hindeodella sp. Hass								O	O	O			O	O
H. sp. Stauffer							X							
H. aculeata Huddle								X					O	
H. alternata Ulrich and Bassler								X					O	
H. alteridius Huddle								X					O	
H. beta							X							
H. breviscula Bond								X					O	
H. conferta Stauffer							X							
H. fishingerensis Stauffer					O		O							
H. germana Holmes								X					O	
H. grandis Huddle										X			O	O
H. lambtonensis Stauffer					O			O						
H. milleri Stauffer							X							
H. cf. milleri								X						
H. modesta Stauffer					O		O							
H. paucidens Bond								X						
H. petila Cooper								O		O				O
H. plumatella Stauffer					O			O						
H. priscella Stauffer								X						
H. recta Ulrich and Bassler								X					O	
H. similis Ulrich and Bassler								X						O
H. subtilis Bond								X					O	
H. triserialis Bond								X					O	
H. sp. 1 Bond								X					O	
H. sp. 2 Bond								X					O	
Hindiodelloides sp. Hass								O	O	O			O	O
H. sp. Stauffer							X							
H. abnormale Stauffer							X							
H. bicristatus Huddle								X					O	
H. cynthiana Stauffer							X							
H. hamulus Bond								X					O	
H. minutus Huddle								O	O				O	O
Icriodus sp. Hass								X					O	
I. arkonensis Stauffer					X									
I. cymbiformist (?) Branson and Mehl			O		O									
I. elegantulus Stauffer					O		O							
I. expansus Branson and Mehl			O		O		O							
I. latericrescens Branson and Mehl					X									
Ligonodina sp. Hass								O	O	O	O		O	O
L. sp. 1 Bond								X					O	
L. sp. 2 Bond								X					O	
L. sp. 3 Bond								X					O	

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													South	North
CONODONTS (con.)														
L. sp. Stauffer							X							
L. bicincta Huddle								X					O	
L. duplicata Stauffer							X							
L. ? erratica Stauffer							X							
L. eva Stauffer							X							
L. falciformis (?) Ulrich and Bassler								X					O	
L. franklinensis Stauffer							X							
L. gouldi (?) Cooper								X					O	
L. subtilis Ulrich and Bassler								X					O	
Ligonodinoides sp. Stauffer							X							
L. leivisensis							X							
L. ohioensis							X							
L. welleri							X							
Lonchodina sp. Hass								O	O	O	O		O	O
L. sp. Stauffer					O		O							
L. disjuncta Stauffer							X							
L. erratica Hinde								O		O			O	
L. inaequalis Stauffer							X							
L. multidens Hibbard								X					O	
L. perarcuata Ulrich and Bassler								X					O	
L. perlonga Ulrich and Bassler								X					O	
Lonchodus princeps Hinde								O		O			O	
Metapalmatodella macrodenta Bond								X					O	
Metaprioniodus biangulatus Huddle								X					O	
Nothognathella sp. Hass								O	O				O	O
N. sp. Stauffer			O				O							
N. angusta Stauffer							X							
N. bogartensis Stauffer							X							
N. delawarensis Stauffer							X							
Oistodus humilis Stauffer			X											
Ozarkodina sp. Hass										X			O	O
O. delicatula Bond								X					O	
Palmatodella sp. Hass								X					O	
P. delicatula Ulrich and Bassler								X					O	
Palmatolepsis sp. Hass								O	O				O	O
P. distorta Branson and Mehl								O	O				O	O
P. elongata								X						
P. flabelliformis Stauffer							X							
P. glabra Ulrich and Bassler								O	O				O	O
P. (?) inequalis Holmes								X						
P. marginatus Stauffer							X							
P. perlobata Ulrich and Bassler								O	O				O	O
P. punctatus Hinde								O		O			O	
P. quadrantinodosa Branson and Mehl								X					O	
P. regularis Cooper								X						
P. rugosa Branson and Mehl								O	O				O	O
P. subperlobata Branson and Mehl								X					O	
P. subricta Miller and Youngquist							X							
P. cf. punctata								X						O
Panderodella maxillaris Ulrich and Bassler								O		O			O	
P. subrecta Holmes										X			O	

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													South	North
CONODONTS (con.)														
Plectodina sp. Stauffer							X							
P. aculeata Stauffer							X							
P. armata Stauffer					O		O							
P. stouti Stauffer							X							
Polygnathus sp. Hass								O	O	O	O		O	O
P. sp. Bond								X					O	
P. basilcus Stauffer							X							
P. comis Stauffer							X							
P. concentricus Ulrich and Bassler								O		O			O	
P. decorosus Stauffer			O		O		O							
P. delicatulus Ulrich and Bassler								O		O			O	
P. germanus Ulrich and Bassler								X					O	
P. nodocostata Branson and Mehl								X					O	
P. pennatuloidea Holmes								X					O	
P. pennatulus Ulrich and Bassler								X					O	
P. pergyratus Holmes								O		O			O	
P. sanduskensis Stauffer					O		O							
P. strongi Stauffer			O		O		O							
P. sublatus Ulrich and Bassler								X					O	
P. cf. P. triangularis Branson and Mehl										X				O
P. webbi Stauffer					O		O							
Polylophodonta sp. Hass								O	O				O	O
P. confluens (Ulrich and Bassler)								O	O				O	O
Prioniodella breviapina Ulrich and Bassler								O		O			O	
P. insolita Stauffer							X							
Prioniodina sp. Hass								O	O	O				O
P. sp. Stauffer					O		O							
P. aversa Stauffer							X							
P. pronus (Huddle)										X			O	O
P. separans Holmes								X					O	
Prioniodus sp. Stauffer							X							
P. affinis Stauffer							X							
P. alabamensis Holmes								O		O			O	
P. alatoides Holmes								O		O			O	
P. alatoideus Cooper								X					O	
P. alatus Hinde								O	O	O	O		O	O
P. (?) alpheus Stauffer							X							
P. alternidens Bond								X					O	
P. (?) bifidus Stauffer							X							
P. bownockeri Stauffer							X							
P. cultratus Ulrich and Bassler							X							
P. idoneus Stauffer							X							
P. longidentatus Stauffer							X							
P. macrocoronatus Cooper								X					O	
P. parvidentatus Ulrich and Bassler							O		O				O	
P. powellensis Stauffer							X							
P. smithi Stauffer							X							
P. tulensis Pander							O		O				O	
Spathodus subrectus (Holmes) Huddle								X					O	
Spathognathodus sp. Hass								O	O	O	O		O	O
S. aciedentatus (Branson)											X			
S. aculeatus (Branson and Mehl)										X			O	O

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CONODONTS (con.)														
S. inornatus (Branson and Mehl)										O	O		O	O
S. subrectus (Holmes)								X					O	
Subbryantodus sp. Hass								O	O	O			O	O
S. sp. Bond								X					O	
S. radians Branson and Mehl								X					O	
S. subangulatus (Holmes)								O	O				O	O
Subprioniodus (?) sp. Stauffer							X							
Synprioniodina sp. Stauffer							X							
S. sp. Bond								X					O	
S. alternata Ulrich and Bassler								X					O	
S. gracilis Stauffer							X							
S. prodenta Bond								X					O	
Telumodina sp. Hass										X			O	O
Trichognathus sp. Hass								O	O	O			O	O
Tricognathus devonicus Stauffer							X							
T. hoffmani Stauffer					X									
PHYLUM BRYOZOA														
Acanthoclema sp. Stumm					X									
A. ohioensis McNair			X											
A. subcatum Hall and Simpson			X											
Anomalotoechus aff. monticula					X									
A. tenera (Bassler)					X									
Ascodictyon stellatum Nicholson and Etheridge					X									
Batostomella obliqua					X									
Botryllopora socialis Nicholson			O		O									
Cryptostomata sp.			X											
Cystodictya hamiltonensis					X									
C. incisurata (Hall)	O		O				O							
Fenestella sp.			X											
F. delicata Meek											O	O		
F. multiporata (?) var. lodiensis											O	O		
Fistulipora corrugatus (?)					X									
F. involvens					X									
F. spinulifera		O	O		O									
F. vesiculata (Hall and Simpson)					X									
Hederella sp. Baker							X							
H. canadensis (Nicholson)			O		O	O	O							
H. cirrhosa Hall			O		O									
H. filiformis					X									
H. magna Hall			X											
Helopora inexpectata McNair			X											
Intrapora (?) irregularis			X											
Monotrypella ohioensis			X											
Paleschara (?) sp.			X											
Polypora sp.					O	O								
Reptaria stolonifera Rolle			O		O		O							
Reteporina striata (Hall)	O		O											
Stictoporina granulifera			X											
Streblotrypa anomala McNair			X											
S. hamiltonensis (Nicholson)	O		O		O		O							
Sulcoretepora deissi McNair			X											

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PHYLUM BRYOZOA (con.)														
Trematopora sp.					X									
Trepostomata sp.			X											
PHYLUM BRACHIOPODA														
Ambocoelia norwoodi Foerste											X			
A. umbonata (conrad) Hall (?)	O	O	O		O		O		O		O			
Athyris lamellosa Leveille											O	O		
A. polita Hall (?)									O	O				O
A. spiriferoides					O	O								
A. vittata Hall	O		O		O	O								
Atrypa elegans Grabau	O	O												
A. reticularis (Linnaeus)	O	O	O		O	O	O							
A. spinosa Hall	O	O												
Aviculopecten fasciculatus					X									
A. Winchelli Meek											O	O		
Barroisella campbelli Cooper							O	O						
Brachyspirifer audaculus		X												
B. macronotus		X												
Brevispirifer lucasensis (Stauffer)	O	O												
Camarophoria kernahani						X								
Camarotoechia sp. Hyde											X			
C. sp. A Hyde											X			
C. contracta Hall									O	O				O
C. cf. eximia Hall										X				
C. cf. horsfordi Hall	O									O				O
C. kentuckiensis Foerste											X			
C. orbicularis Hall									O	O				O
C. prolifica Hall (?)		O	O											
C. sappho		O									O			
C. stephani Hall										X				
Cardiomorpha subglobosa Meek											O	O		
Cariniferella tioga									X					
Centronella ovata Hall	X													
Chonetes arcuatus (?) Hall	X													
C. aurora (?) Hall							X							
C. coronatus (Conrad)	O	O	O		O		O							
C. deflectus		O			O									
C. fragilis			X											
C. hemisphericus	O						O		O					
C. lepidus Hall	O				O			O		O				
C. logani Hall											X			
C. minutes							X							
C. minutes var. hemisphericus							X							
C. mucronatus (?) Hall	O					O	O							
C. scitulus Hall	O			O										
C. cf. scitulus Hall						O			O		O			
C. setiger Hall									X					
C. vicinus	X													
Chonostrophia reversa		X												
Crania crenistriata					X									
C. (?) sp. Baker							X							
C. hamiltonensis					X									
Craniella hamiltonae Hall			O				O							

	Dundee ls.	Delaware ls.	Silica sh.	Ten Mile Creek dol.	Plum Brook sh.	Prout ls.	Olentangy sh.	Huron sh.	Chagrin sh.	Cleveland sh.	Bedford sh.	Berea ss.	Ohio sh.	
													South	North
PHYLUM BRACHIOPODA (con.)														
Craniops cf. hamiltonae						X								
Cryptonella planirostra					X									
Cryptospirifer disjunctus									X					
Cyrtia alta Hall								O	O					O
Cyrtina hamiltonensis	O	O	O		O		O							
Dalmanella tioga (Hall) Williams									O	O				O
D. lepida (?) Hall	X													
Delthyris consobrina		X												
D. duodenarius		X												
D. raricosta		X												
D. sculptilis											X			
Discina humilis Hall									X					
D. lodensis var.									X					
D. newberryi										X				
D. (Orbiculoidea) Newberryi Hall										O	O			O
D. (Orbiculoidea ?) pleurites Hall												X		
Elytha fimbriata						X								
Eunella attenuata						X								
E. lencklaena Hall	X													
Hemipronites sp. (Herrick)											X			
H. crenistria Phil											X			
Hercostrophia robusta Williams			X											
Leiorhynchus clarkei Prosser								O		O				
L. kelloggi Hall			O		O									
L. laura	O	O			O									
L. limitare		O			O			O						
L. lucasi Stewart			X											
L. multicosta					O		O							
Leptaena rhomboidalis		X												
Lingula sp. Baker							X							
L. cf. complanata Williams										X				O
L. cuyahoga Hall										O	O			O
L. cf. densa Hall					X									
L. cf. exilia					X									
L. irvinensis Foerste											X			
L. ligea					O			O						
L. meeki Herrick										O	O			
L. melie Hall										O	O	O	O	
L. (Lingulella ?) membranacea Winchell											O	O		
L. cf. nuda								X						
L. scotica											O	O		
L. spatulata					O			O						
Lingulodiscina (Orbiculoidea) Newberryi Hall												X		
Leiorhynchus globuliforme (vanuxem) var. chagrinanum Hall									X					
L. mesicostale Hall (?)									X					
L. ohioense Prosser									X					
Martiniopsis maia (Billings)		X												
Megastrophia sp.			X											
M. hemisphaerica		X												
M. cf. hemisphaerica		X												
Mucrospirifer sp.			X											

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													South	North
PHYLUM BRACHIOPODA (con.)														
M. mucronatus Conrad					X									
M. pennatus						X								
M. prolificus (Stewart)			X											
Nucleospira concinna	O													
N. cf. minima Weller											X			
Orbiculoidea sp. Prosser											X			
O. herzeri Hall and Clarke										O	O			
O. media					X									
O. newberryi (Hall)											X			
Orthis michelini											X			
O. tioga Hall									X					
O. vanuxemi Hall											X			
Orthothetes inequalis Hall											X			
Paraspirifer sp.			X											
P. bownockeri (Stewart)			X											
Paleoneilo bedfordensis Meek											X			
P. similis									X					
Pentagonia bicostata						X								
Philidostrophia iowaensis		O			O									
Pholidostrophia iowaensis (Owen)	O	O	O											
P. perplana		X												
Productella sp. Hyde												X		
P. sp. A. Hyde												X		
P. sp. B. Hyde												X		
P. artirostrata									X					
P. cf. concentrica Hall												X		
P. hirsuta							O	O						O
P. cf. lachrymosa (Conrad) Hall									O			O		
P. speciosa Hall									X					
P. spinulecosta Hall	O	O	O		O		O							
P. striatula Hall							X							
Productus sp. 1 Meek												X	O	
P. sp. 2 Meek												X	O	
Prothyris Meeki Winchell											O	O		
Protoleptostrophia sp.			X											
P. perplana		X												
Reticularia praematura									X					
Rhipidomella cyclas					X									
R. michelinia (L'Eveille)											X			
R. cf. missouriensis (Swallow) Hall and Clarke											X			
R. vanuxemi Hall	O	O	O			O								
Rhynchonella sagerana Winchell											X			
Romingeria julia (Winchell)											X			
Schizodus cf. chemungensis (Conrad) Hall									X					
S. medinaensis Meek											O	O		
Schizophoria var. parvum			X											
S. propinqua (?)		X	?		?	?	?							
S. striatula (Schlotheim)	O		O		O	O	O							
Schuchertella chemungensis (Conrad) Girty									O		O			
S. herricki Foerste											X			
S. morsei											X			

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PHYLUM BRACHIOPODA (con.)														
Spinocyrtra sp.			X											
Spirifer audaculus (Conrad)	O	O	O											
S. (Trigonotreta) biplicatus Hall												X		
S. bownockeri			X											
S. (Paraspirifer) bownockeri		X												
S. carteri Hall											O	O		
S. disjunctus									O	O				O
S. euryteines Owen			X											
S. macrus Hall	X													
S. marionensis											X			
S. mucronatus					O	O	O							
S. mucronatus var. prolificum			X											
S. sculptilis (?)		X												
S. (Trigonotreta) striatiformis Meek											O	O		
S. cf. varicosus		X												
"Spirifer" venustus						X								
Spiriferina solidirostris White											X			
Strophalosia hystricula Hall									X					
S. muricato Hall									X					
S. truncata (Hall)							X							
Stropheodonta concava Hall	O				O									
S. demissa (Conrad)	O	O	O		O	O	O							
S. hemispherica Hall	X													
S. perplana (Conrad)	X													
S. (Leptostrophia) perplana (Conrad)	O	O	O											
Strophomena (Hemipronites) crenistria Phillips											O	O		
Syringothyris sp. Hyde											X			
S. alta Winchell									O		O			
S. carteri Hall											X			
S. typa											X			
Terebratula mediocres Stewart			X											
Trematospira sp.					X									
Tropidoleptus carinatus (Conrad)	O		O		O	O								
PHYLUM MOLLUSCA														
Class Pelecypoda (Lamellibranchiata)														
Actinodesma erectum (Conrad)	O	O	O		O									
Actinopteria boydii Hall	O				O									
A. descussata Hall	X													
Allorisma (Cercomyopsis) pleuropistha Meek											O	O		
A. ventricosa Meek											O	O		
Avicula speciosa									X					
Buchiola speciosa								X						
Conocardium cuneus		X												
Cryptonella planirostris Hall	X													
Cypricardella bellistriata (Conrad)											X			
Cypricardinia indenta					X									
Edmondia (?) tapesiformis Meek											O	O		
Glyptodesma erectum		X												
Gosselettia triquetra (Conrad)			X											
Grammysia arcuata					X									
G. bellatula					X									

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PHYLUM MOLLUSCA (con.)														
Class Pelecypoda (Lamellibranchiata) (con.)														
G. bisulata (Conrad)		O	O		O									
G. communis Hall									X					
G. constricta					X									
G. (?) hannibalensis Shumard												X		
G. (?) rhomboides Meek												X		
G. cf. subarcuata Hall										X				
G. ventricosa Meek												X		
Leda diberosa var. bedfordensis											X			
L. diversa var. bedfordensis (Herrick)											X			
L. rostellata					X									
Leiopteria dekayi (?) Hall	X													
L. rafinesqui Hall					X									
Leptodesma sp. Prosser									X					
Limoptera sp.			X											
L. macroptera Hall	X													
Lophonychia cordata Stewart			X											
Lunulicardium fragili								X						
Macrodon hamiltoniae Hall											X			
Modiella pygmaoe											X			
Modiomorpha concentrica Hall			X											
M. mytiloides (Conrad)			X											
M. subalata					X									
Nucula sp. Baker							X							
N. corbuliformis					X									
N. cf. glenparkensis Weller											X			
Nuculana sp. Hyde											X			
N. diversa (Schumacker)											X			
N. kentuckiensis Foerste											X			
N. semilaevis Hyde											X			
Nuculites oblongatus						X								
N. cf. oblongatus					O				O					O
N. triqueter						O		O						
N. cf. triqueter Rector						X								
Nyassa recta					X									
Orthoceras sp.					X									
Palaeantina solenoides Hall									X					
Paleoneilo bedfordensis Meek											X			
P. var. constricta (Conrad)											X			
P. cf. tenuistriata								X						
Paracylas sp.			X											
P. elliptica		O				O								
P. proavia (Goldfuss)	O	O												
Parallelodon (?) sp. A Hyde											X			
P. hamiltoniae (Hall)											X			
P. irvinensis (Foerste)											X			
Pholadella radiata					X									
Phthonia sp. Prosser					O				O					
Promacus andrewsi Meek											O	O		
Pterinea flabellum (Conrad)	O				O		O							
Pterinopecten sp. Herrick											X			

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PHYLUM MOLLUSCA (con.)														
Class Pelecypoda (Lamellibranchiata) (con.)														
P. vertumnus					X									
Schizodus sp. Hyde											X			
S. appressus					O		O							
Sphinotus clavulus Hall (?)									X					
S. contractus Hall									X					
Tellinopsis subemarginata					X									
Class Gastropoda														
Bellerophon lineata Hall (?)											O	O		
B. lyra					X									
B. newberryi (?) Herrick											O	O		
B. cf. newberryi		X												
B. cf. pelops Hall	X													
Bembexia sulcomarginata					X									
Callonema cf. bellatula	X													
Cyrotonella mitella					X									
Diaphorostoma lineatum (Conrad)	O		O											
Euomphalus sp.									X					
Loxonema sp. (resembling L. delphenicola) Herrick									O		O			
L. hamiltoniae Hall	X													
Macrocheilus cf. hamiltoniae								X						
Naticonema lineata						X								
Platyceras bucculentum Hall		O	O											
P. carinatum Hall		O	O											
P. dumosum		X												
P. erectum		O			O	O								
P. (Orthonychea ?) lodiense Meek											O	O		
P. rarispinum Hall			O				O							
Pleuronotus deceivi		X												
Pleurotomaria sp. A. Hyde											X			
P. sp. B. Hyde											X			
P. capillaria					X									
P. planodorsalis					X									
P. rotalia					X									
P. subcomarginata (Conrad)	X													
P. (cf. subcomarginata) Herrick									O		O			
P. tertiligera Meek					X									
Porcellia hertzeri		X												
Straparollus sp.							X							
S. cf. S. hecali Hall							X							
S. cf. S. rudis Hall							X							
Styliolina fissurella (Hall)			O		O	O	O	O						
Tentaculites bellulus	O		O											
T. fissurella								X						
T. gracilistriatus Hall							X							
T. scalariformis	O	O												
Tripospira (Pleurotomaria) rotalia					O		O							
Tropidodiscus cytolites (Hall)											X			
Class Cephalopoda														
Acleistoceras (Gomphoceras) sp.		X												
Anaptychus emersoni							X							

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PHYLUM MOLLUSCA (con.)														
Class Cephalopoda (con.)														
Bactrites arkonensis					X									
Centroceras ohioense		X												
Clymenia complanata								X						
Gigantoceras inelegans		X												
Gomphoceras pingue (?) Hall	X													
Goniatites sp. Hyde											X			
G. sp. (resembling Portage sp.) Herrick											X			
G. complanatus (Claypole)								X						
Manticoceras sp. Baker							X							
M. sinuosum								X						
Orthoceras sp. Baker							X							
O. sp. Hyde											X			
O. sp. Stauffer					X									
O. sp. (resembling O. linteum) Herrick											X			
O. arkenese Whiteaves	X													
O. bebryx var. cayuga Hall									X					
Tornoceras sp. Stauffer							X							
T. uniangulare (Conrad)		O			O		O							
Mollusca incertae sedis														
Coleolus acicula								X						
C. tennicinctum (?) Hall	X													
PHYLUM ARTHROPODA														
Class Crustacea														
Subclass Trilobita														
Phacops sp. Rector			X											
P. rana (Green)		O			O	O								
P. rana var. milleri			X											
Proetus macrocephalus Hall		X												
P. rowii		O				O								
Subclass Archaeostraca														
Echinocaris multinodosa Whitfield									X					
E. pustulosa Whitfield									X					
E. sublevis Whitfield									X					
Rhinocaris ehersi			X											
Spathiocaris sp.							X							
S. cushingi										X				
S. williamsi Ruedemann										X				
Subclass Cirripedia														
Plumulites newberryi Whitfield										X				
Turrilepas (?) newberryi (Whitfield) Clarke									X					
Subclass Malacostraca														
Palaeopalaemon newberryi Whitfield									X					
Subclass Ostracoda														
Aechmina crenulata Stewart					X									
A. serrata Stewart			O		O									
Amphissites sp. Stewart			X											
A. bernhageni Stewart and Hendrix							X							
A. carmani							X							
A. shafferi							X							

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PHYLUM ARTHROPODA (con.)														
Class Crustacea (con.)														
Subclass Ostracoda (con.)														
A. subquadratus (Ulrich)			X											
Aparchites sp. indet.					X									
A. anonyma Stewart and Hendrix					X									
Bairdia sp. Stewart			X											
B. bartholomewensis Stewart and Hendrix							X							
B. delawarensis Stewart and Hendrix							X							
B. devonica					X									
B. lenticulata Stewart and Hendrix							X							
B. pseudomagna Stewart and Hendrix							X							
B. unica Stewart and Hendrix							X							
Bertillonella subcircularis					O		O							
Birdsallella tumida Stewart			X											
Bissaculus bilobus Stewart and Hendrix							X							
Bollia sp. Stauffer					X									
Burlella (?) bisulcata Stewart			X											
B. brevispinata Stewart			O		O		O							
B. pseudobrevispinata					O		O							
B. rhomboidalis Stewart			X											
B. sublunata Stewart			X											
Bythocypris sp. Stewart			X											
B. eriensis					X									
B. indianensis Ulrich			O		O									
B. lucasensis Stewart and Hendrix			O		O		O							
B. punctata					X									
B. sanduskyensis					X									
B. subquadrata Stewart			X											
Bythocyproidea eriensis Stewart and Hendrix					X									
B. sanduskyensis Stewart and Hendrix					X									
Colelonella granulifera Stewart and Hendrix							X							
C. plana Stewart			X											
C. punctulifera Stewart and Hendrix							X							
C. scapha (Stewart			X											
Ctenobolbina trilobata Stewart			X											
Ctenoloculina circatricosa (Warthin)							X							
Cytherella (?) bispinulatus Stewart			X											
C. unioniformis Herrick											X			
Dizygopleura euglyphea Warthin					X									
D. oblonga Warthin			X											
D. trisinuata Van Pelt					X									
Eriella robusta Stewart and Hendrix					X									
Euglyphella sigmoidalis var. primitina Warthin			X											
Eukloedenella sp. Stewart			X											
Franklinella novecosta Stewart and Hendrix							X							
F. novecosta var. obesa Stewart and Hendrix							X							
F. septecosta Stewart and Hendrix							X							
Halliella bellipuncta (Van Pelt)			X											
Hamiltonella ohioensis Stewart			X											
H. ohioensis var. subcompressa Stewart			X											
H. punctulifera (Hall)			X											

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PHYLUM ARTHROPODA (con.)														
Class Crustacea (con.)														
Subclass Ostracoda (con.)														
Haploprimitia sp. indet.					X									
H. simplex			O		O		?							
Hollina sp. indet.					X									
Isochilina scapha Stewart			O		O									
Kirkbyella bellipuncta (Van Pelt)			O		O									
Leperditella caranifera					X									
L. dubia					X									
Leperditia (?) subrotunda (?) Ulrich			X											
Lucasella sp. indet.					O		O							
L. cavanifera Stewart and Hendrix					X									
L. dubia Stewart and Hendrix					O		O							
L. mudula Stewart			X											
L. spinulifera Stewart			X											
Macrocypris actula Stewart			X											
Menoeidina subreniformis Stewart			X											
M. subreniformis var. elongata			X											
Moorea bicornuta Ulrich			X											
Nehdentomis prolifica					O		O							
Octonaria crescentiformis Van Pelt					X									
O. quadricostata Van Pelt			X											
Paraparchites granuliferus					O		O							
P. punctuliferus					O		O							
P. subcotunda (Ulrich)			X											
Poloniella cingulata Warthin			O		O									
Ponderodictya ohioensis (Stewart)			O		O		O							
P. unicornis (Van Pelt)					X									
Pontocypris (?) acuminata Ulrich											X			
Primitia seriata Stewart			X											
P. (?) prolifica Stewart and Hendrix							X							
Primitiopsis punctulifera					X									
P. punctuliferus (Hall)			O		O									
Punctoprimitia simplex (Stewart)					X									
Quasillites fordii Coryell and Malkin					X									
Q. obliquus, Coryell and Malkin					O		O							
Q. (?) pseudobrevispinata					X									
Rhombina sp. indet.							X							
Richterina symmetrica Stewart and Hendrix							X							
Ropolonellus (?) dubius Stewart and Hendrix							X							
Sansabella (?) curiosa							X							
Schmidtella anonyma					X									
Senescella crassimarginata Stewart and Hendrix							X							
S. longaeva Stewart and Hendrix							X							
S. longaeva deflecta Stewart and Hendrix							X							
S. marginaspinata Stewart and Hendrix							X							
Tetradella cicatricosa Warthin			O		O		O							
Tetrasacculus bifidus Stewart			X											
T. bilobus Stewart			X											

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													South	North
PHYLLUM ARTHROPODA (con.)														
Class Crustacea (con.)														
Subclass Ostracoda (con.)														
Thrallella mimica							X							
T. phaseolina Stewart and Hendrix							X							
T. susanolla Stewart and Hendrix							X							
Ulrichia conradi Jones			O		O									
U. fragilis Warthin			X											
Crustacea Incerta Sedis														
Acanthodes (?) dublinensis Stauffer							X							
Fucoid markings									X					
PISCES (Fish)														
Acanthapis armatus Newberry		X												
Acantholepis pustulosus Newberry		X												
Actinophorus clarkii Newberry										X				
Aspidichthys clavatus Newberry							O	O						
A. sp. Newberry								X					O	
Asteroptychius elegans Newberry												X		
Asterosteus stenocephalus Newberry		X												
Brontichthys clarki Claypole										X				
Bungartius perissus Dunkle										X				
Callognathus regularis Newberry								X					O	
C. serratus Newberry								O		O				
Cladodus clarki										X				
C. concinnus Newberry								O		O				
C. fyleri Newberry										X				
C. hertzeri Newberry											X			
C. kepleri Newberry										X				
C. parvulus Newberry										X				
C. pattersoni										X			O	O
C. rivi-petrosi										X				
C. Romingeri Newberry												X		
C. sinuatus										X				
C. terrelli Newberry										X				
C. tumidus Newberry										X				
Cladoselache sp.								X						
Coccosteus sp. Newberry		O						O					O	
C. cuyahogae Claypole										X				
C. occidentalis Newberry		X												
Ctenacanthus angustus Newberry												X		
C. clarkii Claypole										O		O		
C. compressus Newberry										X				
C. formosus Newberry										O	O	O	O	
C. furcicarinatus										X				
C. parvulus Newberry										X				O
C. vetustus Newberry								O		O				
Ctenodus wagneri Newberry								O		O				
Cyrtacanthus dentatus Newberry		X												
Dinichthys sp. Newberry											X			
D. clarki										X				
D. corrugatus Newberry										X				
D. curtus Newberry										X				

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PISCES (Fish) (con.)														
D. gracilis Claypole										X				
D. gouldii Newberry										X				
D. herzeri Newberry								X					O	
D. intermedius Newberry								O		O				
D. kepleri Claypole										X				
D. minor Newberry										X				
D. (?) proecursor		X												
D. terrelli Newberry										X				
Dinognathus eurhinus Dunkle and Bungart										X				
Diplognathus mirabilis Newberry										X				
Glyptaspis verrucosus Newberry										X				
Gonatodus brainerdi Thomas												X		
G. hertzeri Newberry								X					O	
Gorgonichthys clarki Claypole										X				
Gymnotrachelus hydei Dunkle and Bungart										X				
Holdenius holdeni Dunkle and Bungart										X				
Hoplonchus parvulus Newberry										X				
Liognathus spatulatus Newberry		X												
Machaeracanthus major Newberry		X												
M. peracutus Newberry		X												
M. sulcatus		X												
Macropetalichthys rapheidolobis Newberry and Orton		X												
M. sullivanti Newberry		X												
Mazodus kepleri												X		
Monocladodus clarki										X				
M. pinnatus										X				
Mylostoma terrelli Newberry										X				
M. variabilis Newberry										X				
Onychodus hopkinsi										X			O	
O. ortoni								X					O	
O. sigmoides Newberry										X				
Oracanthus (?) abbreviatus Newberry		X												
O. fragilis Newberry		X												
O. granulatus Newberry		X												
Orodus sp. Newberry										X				
O. elegantulus Newberry										X				O
O. ramosus												X		
O. variabilis										X				O
Paleoniscus sp. Newberry												X	O	
P. brainerdi Newberry												X		O
Paramylostoma arcualis Dunkle and Bungart										X				
Phaebodus sp.								X						
P. politus Newberry										X				
Polyrhizodus sp. Newberry										X				O
P. modestus Newberry										X				O
Psammodus antiquus Newberry		X												
Rhadonichthys (?) May								O	O					
Rhynchodus crassus Newberry		X												
R. frangens Newberry		X												
R. secans Newberry		X												
Stethacanthus tumidus Newberry												X		

	Dundee ls.	Delaware ls.	Silica sh.	Ten Mile Creek dol.	Plum Brook sh.	Prout ls.	Olentangy sh.	Huron sh.	Chagrin sh.	Cleveland sh.	Bedford sh.	Berea ss.	Ohio sh. — South	Ohio sh. — North
PISCES (Fish) (con.)														
Titanichthys sp.								O		O				
T. agassizii Newberry										X				
T. clarkii Newberry										X				
T. rectus										X				
Trachosteus clarkii Newberry										X				
FOSSIL PLANTS														
Annularia longifolia												X		
Asteroxylon setchelli Read										X				
? Botryococcus braunii Kutzing											O	O		
Calamites sp.								X						
Calamospora hartungiana (Schopf)										?	O	O		
Callixylon Brownii Read and Campbell										X				
C. newberryi (Dawson) Elkins and Wieland							O	O						O
Cladoxylon dawsoni Read										X				
Cypridina blayaci Corsin											X			
C. saturni Unger											X			
Dadoxylon newberryi Dawson								X					O	
Foerstia sp. Read										X				
F. ohioensis White								X						
Fossil wood								O	O	O			O	O
Guycampbella microphylla (Read and Campbell) Hoskins and Cross										X				
Lepidodendron sp.								X						
Lepidostrobus kentuckiensis (Scott and Jeffrey)											X			
L. noei Mathews											X			
Microzygia sp. Read										X				
Periastrom delepinei Corsin										O	O			
P. performatum Scott and Jeffrey										O	O			
P. polyupsilon Read										O	O			
P. reticulatum Unger										O	O			
Pietzschia schulleri Gothan										O	O			
Pitys brownii Read										X				
Plumulina plumosa Clark									X					
Polyxylon sp. Read										X				
Protocalamites dorfi Read										O	O			
Protolepidodendron microphyllum Read and Campbell										X				
Protocalvinia huronensis (Dawson) Dawson								X						
P. ravenna White								X						
Pseudobornia inornata (Dawson) White								X						
Reimannia indianensis Read and Campbell										X				
Reimanniopsis indianensis (Read and Campbell) Hoskins and Cross										X				
Seaweeds (Branching) unidentified			X											
Siderella sp. Read										X				
Sporangites huronensis Dawson							O	O						
Steloxylon irvingense Read and Campbell										X				
Stenokoleos setchelli (Read and Campbell) Hoskins and Cross										X				
Tasmanites sp. Read										X				
T. sp. Rector		O			O			O						

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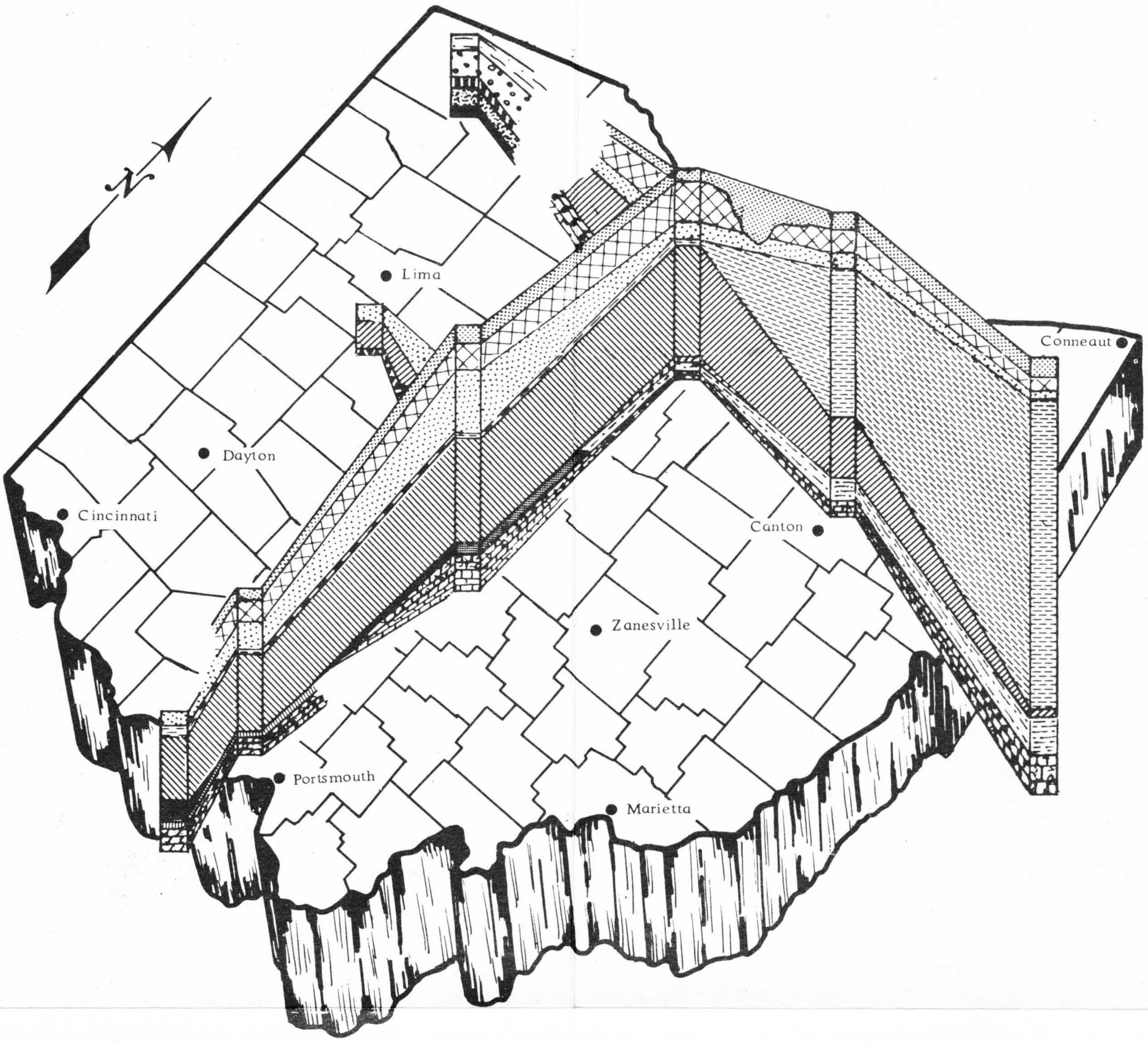
Plate 1

Generalized fence diagram of the Devonian - Mississippian Shale sequence



Legend

- Berea Sandstone
- Bedford Shale
- Bedford-Berea (Mississippian - Undifferentiated)

- Cleveland Shale
- Chagrin Shale
- Huron Shale
- Ohio Shale
- Antrim Shale

- Olentangy Shale
- Prout Limestone
- Plum Brook Shale
- Ten Mile Creek Dolomite
- Silica Shale
- Delaware Limestone
- Dundee Limestone

- Columbus Limestone
- Hillsboro Sandstone
- Greenfield Dolomite

0 500 1000 1500 Feet

Vertical Scale

Plate 2
Structure-contour map of the top of the Bedford shale

Figures indicate the approximate elevation, in feet, of the top of the Bedford shale. Figures preceded by a minus sign (-) indicate elevations below sea level.

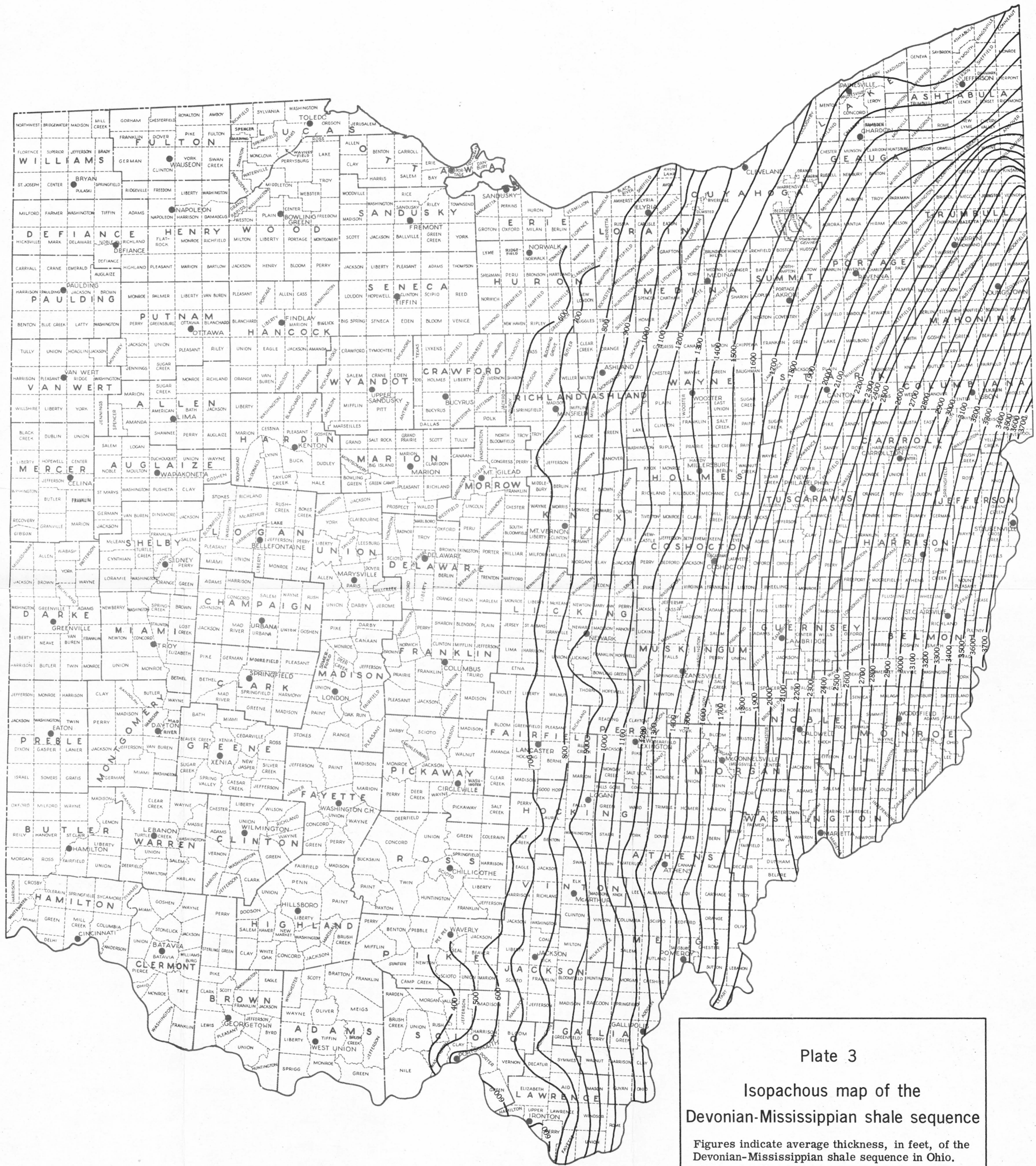


Plate 3

Isopachous map of the Devonian-Mississippian shale sequence

Figures indicate average thickness, in feet, of the Devonian-Mississippian shale sequence in Ohio.