The Mississippian and Pennsylvanian (Carboniferous) Systems in the United States—Ohio

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Historical review and summary of areal, stratigraphic, structural, and economic geology of Mississippian and Pennsylvanian and Lower Permian rocks in Ohio

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THE MISSISSIPPIAN AND PENNSYLANIAN (CARBONIFEROUS) SYSTEMS IN THE UNITED STATES—OHIO

By HORACE R. COLLINS [1]

ABSTRACT

Carboniferous rocks in Ohio are present at the surface over most of the eastern half of the State and have been intensively studied for more than 150 years. All Ohio's coal and sandstone and most of its clay and shale resources are derived from units of this age. Much of the work on the Ohio Carboniferous is oriented toward the economic possibilities of these rocks. The stratigraphic classification of the Pennsylvanian (upper Carboniferous) was established originally to emphasize the economic importance of the subdivisions.

The Mississippian (lower Carboniferous) is predominantly clastic deposits; the Pennsylvanian is a complex repetitive sequence of sandstone, mudstone, shale, limestone, coal, and clay. The contact between the Mississippian and Pennsylvanian is everywhere marked by a major disconformity.

Biostratigraphically, the marine carbonate units of both the Mississippian and the Pennsylvanian have been zoned and correlated with the U.S. midcontinent region on the basis of invertebrate microfossils; Pennsylvanian rocks also have been zoned and correlated with the northern Appalachian region on the basis of plant macrofossils. Invertebrate macrofossils are important in both regional correlation and age assignment.

The Carboniferous of Ohio is not structurally complex, although important exceptions are found in the southeastern part of the State. The contacts with both the underlying Devonian and the overlying Permian Systems are gradual and are not marked by recognizable disconformities. The break between Permian- and Pennsylvanian-age rocks, however, is a controversial matter and is made on the basis of paleontology and not lithology.

INTRODUCTION

To most present-day workers, the Carboniferous of Ohio normally includes only the Mississippian and Pennsylvanian Systems; however, most authors of the middle and late 1800's included rocks now classified as Permian (or Permian-Pennsylvanian transition) in the Carboniferous. Prosser (1905, p. 2) assigned the Upper Barren Coal-measures to the Dunkard Formation and placed the formation in the Permian (?) System; he did not, however, include the Permian in the Carboniferous. The general classification of Devonian, Carboniferous, and Permian in Ohio has changed little since Prosser's 1905 revision. A significant name change, however, was made in the early 1900's when most American geologists generally accepted the terms Mississippian and Pennsylvanian for the now little-used Carboniferous. A brief discussion of the Permian age question and of the rocks traditionally assigned to this system will be given later. In following the usual practice of Ohio geologists and the current practice of the U.S. Geological Survey, I did not include Permian rocks in the Carboniferous System.

Outcrops of Carboniferous-age rocks in Ohio are confined approximately to the eastern half of the State (fig. 1). Mississippian units crop out along a band extending more than 480 km (300 mi) from Ashtabula and Trumbull Counties (see fig. 2 for county locations) on the northeast, westward to Erie and Huron Counties in the north-central part of the State, and then southward to Adams and Scioto Counties on the Ohio River. The outcrop belt ranges from 8 km (5 mi) to slightly more than 80 km (50 mi) in width. Lamborn and others (1938, p. 43) estimated that Mississippian outcrops are present over an approximate area of 8,586 mi^2 (22,238 km^2). Except in the southernmost part of the State, outcrops are largely mantled by glacial drift. Mississippian rocks dip under cover to the south-southeast, where they are overlain by Pennsylvanian-age units. A small area of Mississippian-age rocks is present in Fulton, Defiance, and Williams Counties in extreme northwestern Ohio. This area is covered by thick glacial drift, and no outcrops are known.

South of Ross County, beyond the glacial boundary, Mississippian exposures are common. Many excellent exposures are also found in the narrow belt east of the drift limit from Ross County north to Holmes County. In the areas covered by glacial drift, exposures are less common; however, along principal streams near the edge of the drift boundary, good outcrops can commonly be found. Away from the glacial boundary, where drift is thicker,

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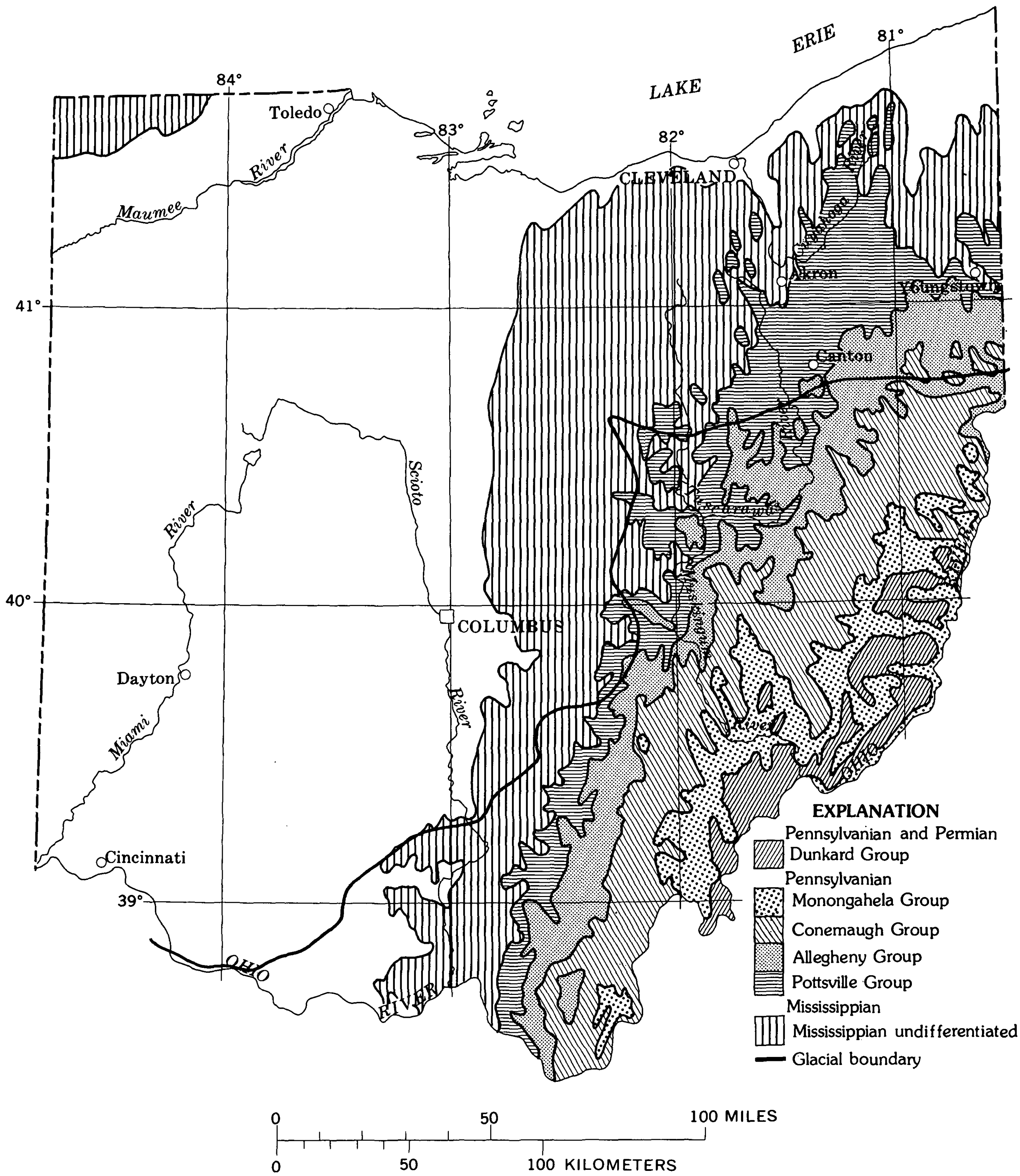

FIGURE 1.—Extent of Carboniferous rocks of Ohio (modified from King and Beikman, 1974).

FIGURE 2.—Location of counties in Ohio.

bedrock crops can generally be found only along major streams.

Highway cuts and quarries provide additional exposures in areas where glacial drift obscures outcrops. Hyde (1953) and Pepper and others (1954) discussed various aspects of middle and Lower Mississipian stratigraphy on a more or less statewide basis; their reports are invaluable guides to specific outcrops. Szmuc (1970) described the Mississippian of northeastern Ohio and gave many section localities.

Pennsylvanian-age rocks lie to the east and south of the Mississippian outcrop belt and cover approximately the easternmost third of the State. Most of the Pennsylvanian rocks lie beyond the limit of glacial drift; exposures are numerous. Glacial drift mantles parts of the section in the northeasternmost counties; however, the drift is relatively thin, and good exposures can generally be found. Highway cuts in many places provide the best sections in the glaciated parts of the system. Active open-pit mines generally provide excellent exposure; however, after mining has been completed, rapid modern reclamation methods essentially eliminate strip mines as stratigraphic study areas. Denton and others (1961) gave many section descriptions and localities representative of the Pennsylvanian in Ohio; their report is useful as a general guide to the system in the State.

Permian-age rocks cap the Pennsylvanian System in the eastern and southeastern counties of Athens, Belmont, Meigs, Monroe, Morgan, Noble, and Washington. Outcrops of Permian and Permian-Pennsylvanian transition-age rocks are abundant throughout their area of occurrence. The abundance of incompetent red mudstone in this part of the section, as well as in the underlying Monongahela and Conemaugh Groups, leads to a high incidence of slumping, which masks many outcrops. Highway cuts, however, particularly along the interstate system, provide excellent exposures.

The stratigraphic nomenclature used in this paper has not been reviewed by the Geologic Names Committee of the U.S. Geological Survey. The nomenclature used here conforms with the current usage of the Ohio Department of Natural Resources, Division of Geological Survey.

HISTORY OF CLASSIFICATION

MISSISSIPPIAN

The present classification (fig. 3) of the Mississippian System (lower Carboniferous) in Ohio, unlike that of the Pennsylvanian System (upper Carboniferous), was largely developed by geologists working principally for the State geological survey. In the first annual report of the newly organized geological survey, Briggs (1838, p. 79–80) introduced the term Waverly sandstone series for all the rocks lying above what is now recognized as the Ohio Shale (Devonian) and below a conglomerate presently known to correlate with the basal Pennsylvanian-age Sharon conglomerate. Andrews (1871, p. 83) named the Upper Mississippian Maxville Limestone, which he described as being discontinuous and lying on the Logan Sandstone group; this was the first such usage of Logan in the geological literature of Ohio. Andrews also referred to the Logan Sandstone group as the Upper Waverly group. Newberry (1870, p. 21) listed the principal elements of the Waverly group in northern Ohio as being, in ascending order, Cleveland Shale, Bedford Shale, Berea Grit, and Cuyahoga Shale." The Cleveland Shale was subsequently assigned to the underlying Devonian-age Ohio Shale.

It remained for Hicks (1878, p. 216) to describe the Sunbury Formation and formally introduce that name. Hicks (p. 216–217) introduced also the term Black Hand for a thick sandstone and conglomerate in the Black Hand gorge on the Licking River. The Black Hand sandstone was subsequently made a member of the Cuyahoga Formation.

Although some minor differences existed in the terminology and in the precise positions of boundaries, the basic classification of the Mississippian section in Ohio was well established by the late 1800's. Prosser (1905, p. 4) listed the accepted units, in ascending order, as Bedford Shale; Berea Grit, Sunbury Shale; Cuyahoga, Black Hand, and Logan Formations; and Maxville Limestone". With the exception of the Black Hand Formation, Prosser's classification is still valid.

On the basis of several facies that could be recognized within the unit, Hyde (1915) proposed a subdivision of the Cuyahoga Formation. Hyde divided the outcrop region into several areas that had few lateral changes and, in general, had vertically uniform lithologies (fig. 4). Each facies, consisting of one to several members (table 1), was given a name taken from an area that typified a

TABLE 1.—*Subdivision of the Cuyahoga Formation proposed by Holden (1942)*[1]

1. Henley shale facies: Henley shale member.	2. Hocking Valley conglomerate facies: Black Hand conglomerate member. Fairfield sandstone member. Lithopolis siltstone member.
3. Granville shale facies: Black Hand siltstone member. Raccoon shale member.	4. Toboso conglomerate facies: Black Hand conglomerate member. Pleasant Valley shale and sandstone member.
5. Killbuck shale facies: Black Hand shale member. Armstrong sandstone member. Burbank shale and sandstone member.	6. River Styx sandstone facies: Black Hand sandstone member. Armstrong sandstone member. Rittman conglomerate submember.
7. Tinkers Creek shale facies: Meadville shale member. Sharpsville sandstone member. Orangeville shale member. Aurora sandstone submember.	

[1] Modified by Holden from Hyde (1915).

SYSTEM	GROUP	FORMATION OR BED	MEMBER
PERMIAN	Dunkard	Washington (No. 12) coal	
PERMIAN—PENNSYLVANIAN	Dunkard		
PENNSYLVANIAN	Monongahela	Waynesburg (No. 11) coal Pittsburgh (No. 8) coal	
PENNSYLVANIAN	Conemaugh	Ames Limestone	
PENNSYLVANIAN	Allegheny	Upper Freeport (No. 7) coal Brookville (No. 4) coal	
PENNSYLVANIAN	Pottsville	Sharon Conglomerate	
MISSISSIPPIAN	Waverly	Maxville Limestone	
MISSISSIPPIAN	Waverly	Logan Formation	Vinton Sandstone Allensville Conglomerate Byer Sandstone
MISSISSIPPIAN	Waverly	Cuyahoga Formation	Berne Conglomerate Black Hand Sandstone Portsmouth Shale Buena Vista Sandstone Henley Shale
MISSISSIPPIAN	Waverly	Sunbury Shale	
MISSISSIPPIAN	Waverly	Berea Sandstone	
MISSISSIPPIAN	Waverly	Bedford Shale	Sagamore Shale Euclid Shale
DEVONIAN		Ohio Shale	Cleveland Shale Chagrin Shale Huron Shale

FIGURE 3.—Generalized stratigraphic column of the Carboniferous section of Ohio (including immediately overlying and underlying units).

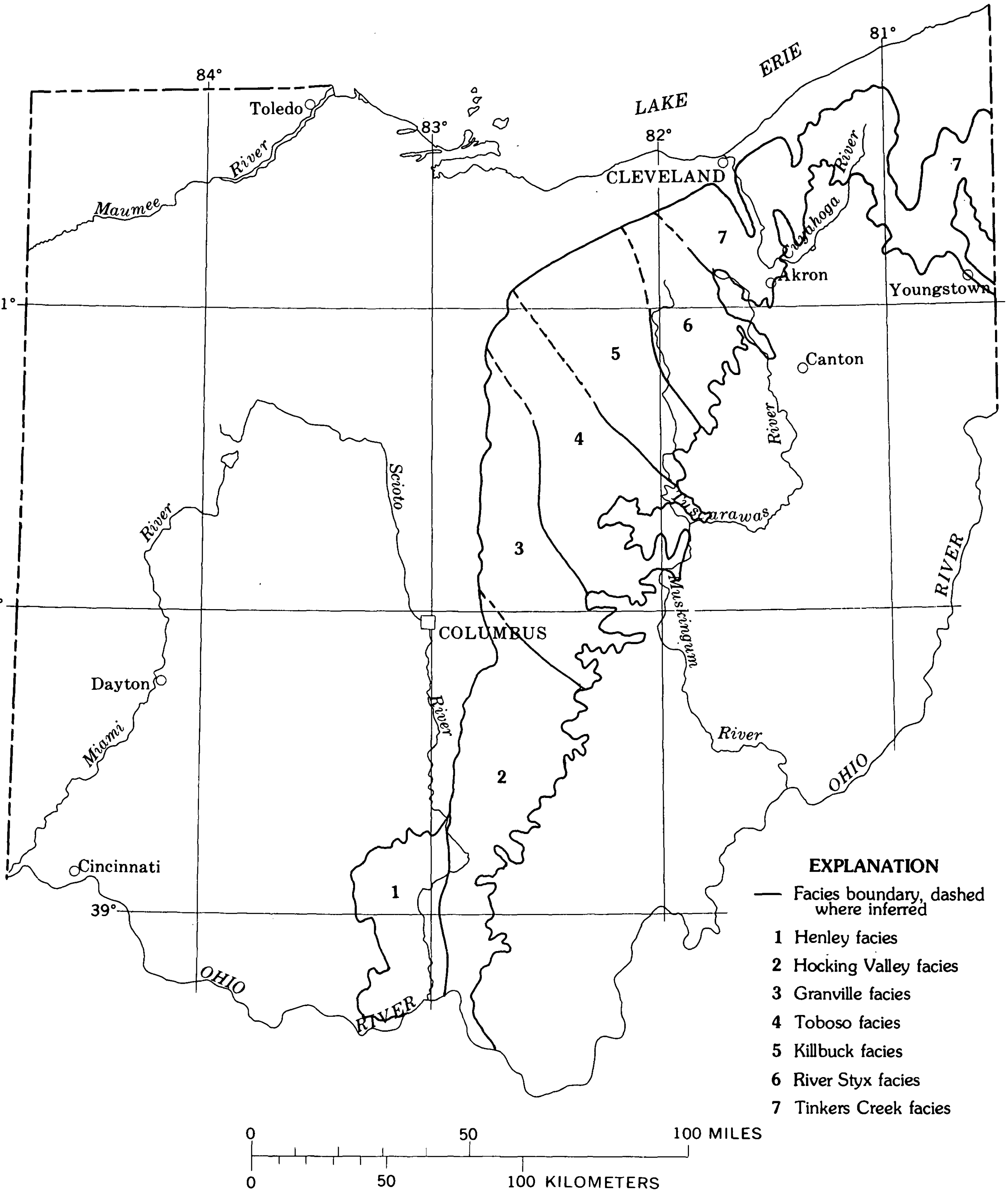

FIGURE 4.—Extent of proposed facies of the Cuyahoga Formation; Hocking Valley, Granville, and Toboso facies from Hyde, 1915, figure 1; Henley, Killbuck, River Styx, and Tinkers Creek facies from Holden, 1942, figure 2 (modified from Wolfe and others, 1962).

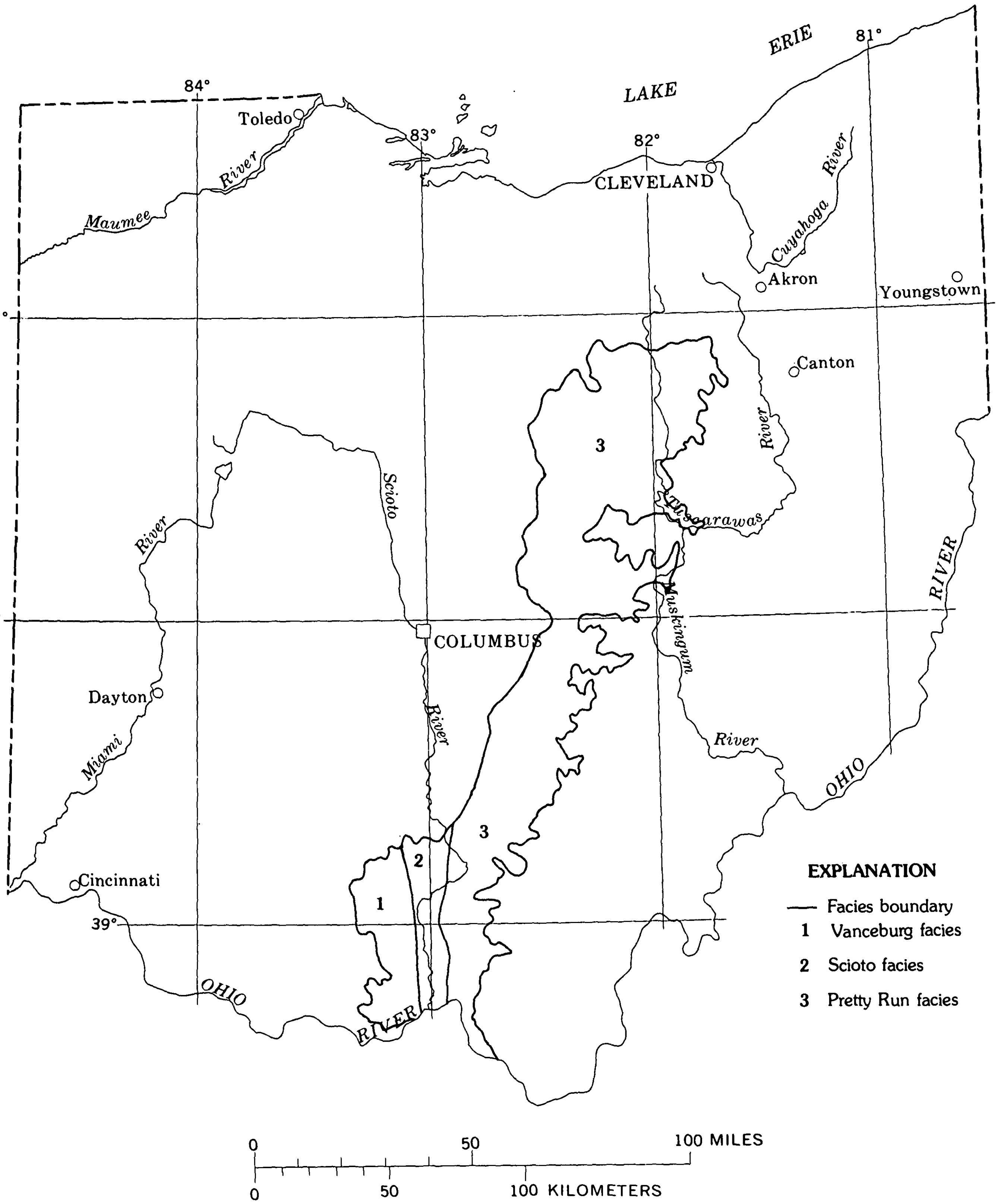

FIGURE 5.—Extent of proposed facies of the Logan Formation, from Holden, 1942, figure 3 (modified from Wolfe and others, 1962).

TABLE 2.—*Subdivision of the Logan Formation proposed by Holden (1942)*

1. Vanceburg siltstone facies:
   - Vinton sandstone member.
   - Churn Creek siltstone and shale member.
   - Vanceburg siltstone member.
   - Rarden shale member.
   - Buena Vista sandstone member.
2. Scioto Valley shale facies:
   - Vinton sandstone member.
   - Portsmouth shale member.
   - Buena Vista sandstone member.
3. Pretty Run sandstone facies:
   - Rushville shale member.
   - Vinton sandstone member.
   - Allensville conglomerate member.
   - Byer sandstone member.
   - Berne conglomerate member.

particular facies. Holden (1942), following Hyde's original proposal, enlarged and in part modified the subdivision of the Cuyahoga and extended the concept into the overlying Logan Formation (fig. 5; table 2).

However, Hyde's and Holden's proposed subdivisions of the Cuyahoga and Logan Formations to date have not been widely used.

PENNSYLVANIAN

The Pennsylvanian sequence in Ohio has four major subdivisions. These subdivisions were established on practical rather than lithologic or paleontologic criteria and basically follow the original classification established by Rogers (1858) for Pennsylvania. The basis for the subdivisions, as Rogers' original names suggest, is the relative abundance of minable coal. Rogers' units, in ascending order, were Seral Conglomerate, Lower Productive (Older) Coal Measures, Lower Barren (Older) Coal Measures, Upper Productive (Newer) Coal Measures. Various geologists, working primarily in Pennsylvania, made a number of modifications in the original proposal, and Prosser (1905) adopted for Ohio the names and overall classification accepted at that time. In ascending order, the units are Pottsville, Allegheny, Conemaugh, and Monongahela. These units, which in Ohio have been called formations, series, measures, and groups, are presently considered to be groups.

The group boundaries as presently used in Ohio are: Pottsville—Sharon conglomerate to the base of the Brookville (No. 4) coal; Allegheny—base of the Brookville coal to top of the Upper Freeport (No. 7) coal; Conemaugh—top of the Upper Freeport coal to the base of the Pittsburgh (No. 8) coal; Monongahela—base of the Pittsburgh coal to the top of the Waynesburg (No. 11) coal. The Waynesburg coal marks the base and the Washington (No. 12) coal the top of a Permian-Pennsylvanian transition zone, which includes the lower part of the Dunkard Group. Strata above the Washington coal include the upper part of the Dunkard, which is presently considered to be Permian in age.

Within the four groups, individual economically important and persistent units have been named. However, many of these units, considered to be beds according to the American Code of Stratigraphic Nomenclature are, although named, not persistent or economically important.

More than 100 individual beds have been named in the Pennsylvanian section of Ohio. (See tables 4–8.) The large number of named units is related, in part, to the early geologic concept that sedimentary rock units were tabular in nature and could correlated over a wide geographic area. This concept was aided in Ohio by the fact that a few Pennsylvanian-age beds do have a reasonably wide areal extent and also by the fact that, because of the repetitive nature of the sequence, many beds have a general although not precise relationship to similar beds at different localities. The proliferation of named units was also, in part, a response to the need of a growing industrial society to have identifying terms to use in the exploration and development of the region's mineral resources.

A second system of classification, proposed by Stout (1931), was based on lithologic and paleontologic consideration. Stout noted that a threefold division of the Pennsylvanian could be made on the basis of whether the calcareous beds were deposited under marine or freshwater conditions. Stout's classification consisted of (1) a lower unit encompassing all the rocks from the base of the Sharon conglomerate to the base of the Hamden limestone, containing marine shale and limestone, (2) a middle transitional unit from the base of the Hamden to the top of the Skelley limestone, containing both marine and freshwater limestone, and (3) an upper unit from the top of the Skelley limestone to the top of the Waynesburg coal, containing only freshwater limestone. A minor change in Stout's boundary between the lower and middle units would be needed to accommodate the fact that the type Hamden limestone was subsequently shown to be nonmarine (Sturgeon and others, 1958). For unknown reasons, possibly entrenchment of the earlier system, lack of correlation with the more clastic section of neighboring Pennsylvania and West Virginia, or some dissatisfaction by the proposer, this classification was never adopted.

TABLE 3.—*Basic types of cyclothems in the Pennsylvanian System of Ohio*[1]

Lower unit	*Middle unit (transitional)*	*Upper unit*
1. Clay, nonmarine. Shale and sandstone, largely marine. Iron ore, marine. Limestone, marine. Coal, nonmarine.	Cycle same as 2 in lower unit.	Cycle same as 5 in middle unit.
2. Clay, nonmarine[2]. Shale and sandstone, largely marine. Limestone, marine. Coal, nonmarine.	4. Clay nonmarine[3]. Limestone, nonmarine. Shale and sandstone, partly marine. Limestone, marine. Coal, nonmarine.	6. Clay nonmarine[3]. Limestone and calcareous shale, nonmarine. Coal, nonmarine.
3. Clay, nonmarine. Shale and sandstone, probably brackish water or marine. Shale, fossiliferous, brackish water. Coal, nonmarine.	5. Clay, nonmarine. Limestone, nonmarine. Shale and sandstone, nonmarine. Coal, nonmarine.	7. Clay, nonmarine. Shale and sandstone, nonmarine. Coal, nonmarine.

[1]From Stout, 1931.
[2] Commonest cycle in lower unit.
[3] Distinctive cycles of the unit in which they occur.

The cyclical nature of Pennsylvanian strata was noted by some early workers, but the concept of the cyclothem was proposed and elaborated on by Weller (1930, 1931) and Wanless and Weller (1932). Stout (1931) also recognized cycles in Ohio and described seven basic types (table 3) and their distribution within his proposed threefold classification of the Pennsylvanian section. The concept of the cyclothem has been used extensively by most Pennsylvanian workers in Ohio and has proved to be an extremely valuable field tool. A few workers have used cyclothems in a formal stratigraphic sense in reporting field investigations.

More recently, a number of workers have called attention to the deltaic nature of Pennsylvanian rocks. The similarities between the sedimentary framework of Pennsylvanian rocks in the northern Appalachian basin and the sediments of modern deltas are so great that Ferm and Cavaroc (1969) used the same terminology for specific recent environments and for ancient environments. No comprehensive classification, however, has been offered for the complex sequence of Pennsylvanian rocks on the basis of deltaic models.

PERMIAN

As stated earlier, rocks now considered to be Permian-Pennsylvanian transition in age were, prior to 1900, included in the Carboniferous. The U.S. Geological Survey included the Permian in the Carboniferous as late as 1957. Rogers' (1858) Upper Barren Measures was subsequently named the Dunkard Series (originally Dunkard Creek Series) by White (1891). White placed the lower boundary of the Dunkard at the top of the Waynesburg coal and included all the overlying strata in the Appalachian region in the Dunkard. Fontaine and White (1880) had previously correlated the rocks in this interval as Permian in age. The break between the Pennsylvanian and Permian is not lithologic, but rather is based primarily on the presence of *Callipteris conferta*, considered by many to be an index fossil of the Permian. Cross (1958) failed to find undisputed *Callipteris conferta* below the Washington coal. In November 1959, members of the U.S. Geological Survey and the Pennsylvania, Ohio, and West Virginia Geological Surveys agreed to consider the Washington Formation (lower Dunkard) as Pennsylvanian and Permian in age and the Greene Formation (upper Dunkard) as Permian in age. Berryhill and Swanson (1962, p. C43) placed the base of the Permian at the base of the Washington coal. Rocks between the base of the Waynesburg coal and the base of the Washington coal were designated the Waynesburg Formation of Pennsylvanian and Permian age. The Waynesburg Formation has not been formally used in Ohio; however, the base of the Permian has been accepted as being at the position of the Washington coal (Collins and Smith, 1977).

The lack of a lithologic break in the sequence from basal Conemaugh through the highest rocks in the section, a thickness of more than 360 m (1,200 ft), coupled with only a gradual waning of Pennsylvanian floral types and only generally an increase in Permian flora, have led some workers (Gillespie and Clendening, 1969; Gillespie and others, 1975; Clendening, 1975) to argue for a Pennsylvanian age for all rocks now classified as Permian. The age of the Dunkard is still an enigma.

GEOLOGIC SETTING

Basal Mississippian rocks in Ohio are, at the surface, everywhere underlain by the Devonian-age Ohio Shale. The Ohio Shale in central and southern Ohio consists of black to brownish-black fissile shale. In the northern part of the State, the Ohio Shale can be subdivided, in ascending order, into the

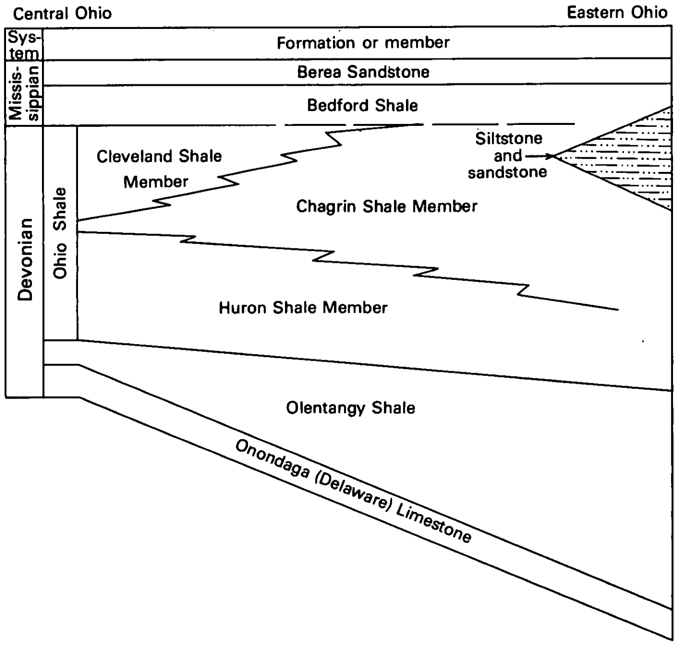

FIGURE 6.—Schematic cross section showing thickness changes of Devonian shales in eastern Ohio; lens of siltstone and sandstone shown represents the occurrence of these clastic rocks in several stratigraphic positions within the Chagrin Shale Member of the Ohio Shale as far west as Guernsey County (modified from Janssens and de Witt, 1976).

Huron, Chagrin, and Cleveland Shale Members. The Cleveland Member is a predominantly black bituminous shale containing intercalated beds of gray shale and siltstone of the interfingering Chagrin Member. The Chagrin Member is composed of gray shale and siltstone and interfingers to the west with the Cleveland Member (fig. 6). In northern Ohio along Lake Erie to the Ohio-Pennsylvania border, the Mississippian Bedford Shale is underlain by the Cleveland Member on the west and the Chagrin Member on the east.

The nature of the contact between the Devonian and Mississippian has not been studied in great detail; however, little evidence for a major unconformity at this contact is seen. Where adjacent rock types are relatively dissimilar (that is, red Bedford over black Ohio Shale) the contact is distinct and easily identified. However, where the Bedford consists of gray shale overlying gray shale and siltstone of the Chagrin shale, the contact is indistinct and cannot be readily identified; in such areas some workers have included the Bedford in the Devonian.

The contact between the Mississippian and the Pennsylvanian is clearly disconformable. The contact between the upper Mississippian Maxville Limestone and the middle Mississippian Logan Formation is also disconformable, as first noted by Morse (1910). Hyde (1953, p. 58) suggested that the "absolute range of relief on the pre-Pennsylvania [sic] erosion surface may amount to 350 or even 400 feet [107 to 122 m]." Local relief, however, is more probably about 15 to 23 m (50 to 75 ft). Basal Pennsylvanian rocks may rest directly on the Maxville Limestone, the Logan Formation, or even the Cuyahoga Formation, depending on the degree of post-Mississippian erosion in the area. Pennsylvanian beds in the Pottsville Group as high as the Massillon sandstone are reported as being in direct contact with the Cuyahoga Formation.

The contact between the Pennsylvanian and overlying Permian definitely lacks a clear-cut break of any type. Rocks presently assigned to the Permian and Permian-Pennsylvanian transition are indistinguishable from beds in the underlying Monongahela and Conemaugh Groups, which are considered unquestionably Pennsylvanian in age.

STRUCTURE

The Carboniferous rocks of Ohio are not structurally complex except in the region of the Burning Springs anticline, the Cambridge arch, and the Parkersburg-Lorain syncline, which will be discussed later. Mississippian and Pennsylvanian rocks were deposited on the west and northwest flank of the Pittsburgh-Huntington basin. For the most part, units dip gently (0°20′) southeast into the basin, but along the northern margin of the basin the dip component is southerly; in the southernmost part of the State, the dip is somewhat easterly. This regional trend is broken locally by minor structures generally considered to be largely penecontemporaneous features. Faults are relatively rare and generally have displacements of less than 1 m.

The principal structural features affecting Carboniferous rocks in Ohio are the post-Permian-age Burning Springs anticline, the Cambridge arch, and the Parkersburg-Lorain syncline (fig. 7). The northernmost part of the Burning Springs anticline crosses the Ohio River from West Virginia near Newport in Washington County and extends to about the Washington-Monroe County line, where it disappears on the surface. The trend of the Burning Springs anticline is north-south and follows the westward pinchout of the Silurian-age Salina F_4 salt. The structure may be the result of imbricate thrust faulting caused by termination of the décollement glide zone of a westward-northwestward-moving thrust sheet (Gwinn, 1964; Rodgers, 1963; Woodward, 1959).

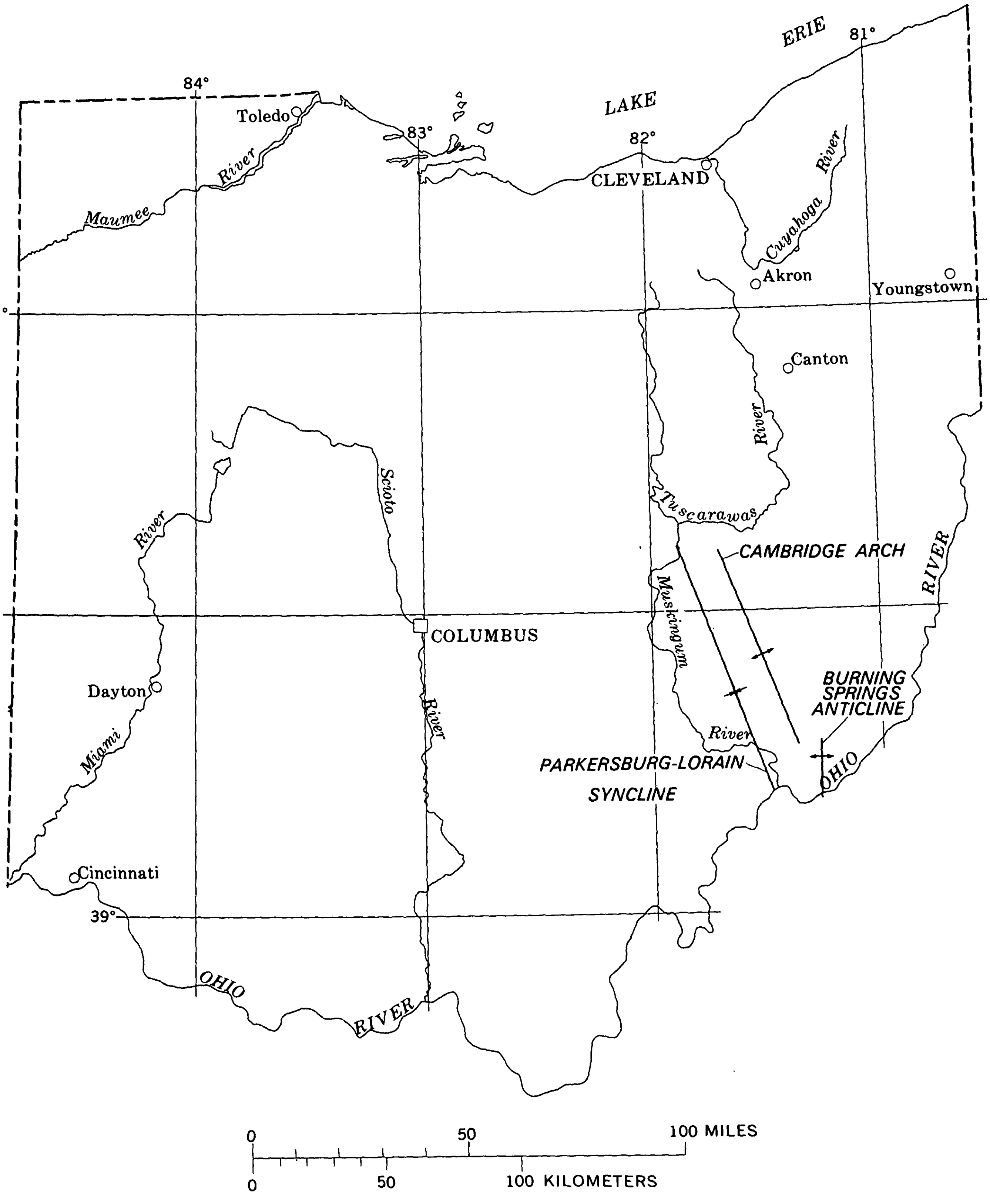

FIGURE 7.—General trend of the principal structural features of southeastern Ohio.

The Cambridge arch is a prominent structural feature that affects Carboniferous rocks in southeastern Ohio. This feature trends northwest-southeast from northern Washington County through Cambridge in central Guernsey County and into Muskingum County. Mapping by Collins and Smith (1977) in Washington County indicates that this feature is not, as some workers have suggested, a continuation of the Burning Springs anticline. Clifford and Collins (1974) reported that the Cambridge arch follows the pinchout of the Silurian-age Salina E salt; east of the pinchout, elevations of the Pittsburgh coal are about 91 m (300 ft) higher than those to the west. Only a gentle southeastward dip is found below the salt. These authors interpreted the structure to be the result of movement of a southeastward-thickening block of supra-Salina rocks northwestward along a salt glide plane. A postulated nearly vertical tear fault (or series of faults) marks the western limit of this movement.

The Parkersburg-Lorain syncline is a broad troughlike structure that trends northwest from Washington County to Lorain County. Stout and others (1935, p. 898) considered it to be "the most outstanding structural feature of the eastern half of the state * * * which can be traced on surface beds from Parkersburg [Wood County, West Virginia] on the Ohio River, northwest to Lorain County [Ohio] at Lake Erie." Little work beyond that of Stout and others has been done on this structural feature, and its precise nature remains largely unknown.

LITHOSTRATIGRAPHY

MISSISSIPPIAN

The Mississippian System in Ohio consists of six formations, which are, in ascending order, Bedford Shale, Berea Sandstone, Sunbury Shale, Cuyahoga Formation, Logan Formation, and Maxville Limestone. Thicknesses of the clastic units differ considerably, but average on the outcrop 29, 11, 6, 103, and 51 m (95, 35, 20, 339, and 166 ft), respectively. The Maxville Limestone, because of intensive post-Mississippian erosion, differs extremely in thickness, generally not exceeding 15 meters (50 ft) on the outcrop. The stratigraphy of most of these formations has been widely studied; however, the Cuyahoga and Logan have undoubtedly received the most attention because of efforts to subdivide these units.

With the exception of the Maxville Limestone, the Mississippian rocks of Ohio form a northwestward-thickening clastic sequence of shale, sandstone, and conglomerate. Erosion has everywhere reduced the original thickness of the Mississippian; however, as much as 305 m (1,000 ft) of clastic strata is reported by Hyde (1927, p. 43) in Vinton County. The Maxville Limestone is thickest in the southern part of the State and is absent in the northern part, but the original thickness trend of the unit is not apparent because of severe erosion, which has completely removed the unit in many areas.

BEDFORD SHALE

The Bedford Shale, as stated above, rests directly on Devonian-age shale and in many places is essentially indistinguishable from the underlying beds. The formation takes its name from the town of Bedford in Cuyahoga County. The Bedford in southern Ohio consists largely of bluish-gray sandy shale containing, particularly in the upper part, sandstone and siltstone. In the central and north-central parts of the State, the unit becomes red to reddish brown, although bluish-gray shale is also present; the unit is also much more argillaceous than it is to the south. Both the red and gray shales are used by the ceramic industry in Franklin and Delaware Counties. North from Franklin County to Lorain County, the amount of red shale increases, and red shale predominates in the north. From Cuyahoga County to the Ohio-Pennsylvania line, red shale is largely replaced by gray to blue-gray shale and interbedded siltstone. Two such massive siltstone members in Cuyahoga County have been named the Sagamore and Euclid siltstones (fig. 3). The Euclid member was formerly quarried for flagstone. In extreme eastern Ashtabula and Trumbull Counties the Bedford rests on the Cussewago Sandstone, which is the basal Mississippian unit in this area.

BEREA SANDSTONE

The Berea Sandstone takes its name from the town in Cuyahoga County. This unit as well as the underlying Bedford has been described and discussed in detail by Pepper and others (1954), who made a classic report and an in-depth analysis of these units. In southern Ohio, the Berea is represented by light-gray to buff siltstone, which in many areas cannot be distinguished from the underlying Bedford. From about central Ohio (Franklin County) north to the type area and east to the Pennsylvania-Ohio border, the unit consists of fine- to medium-grained sandstone. In the north-central part of that area, the basal part of the Berea is represented by a massive channel sand that reaches a thickness of more than 72 m (235 ft) at the Buckeye quarry at South Amherst, Lorain County (Pepper and others, 1954, p. 28). In many areas, massive channel sand is overlain by ripple-marked thin-bedded sandstone.

SUNBURY SHALE

The Sunbury Shale, which was named for the village in Delaware County, consists of thinly bedded fissile carbonaceous black shale. The unit is thin, averaging only about 6 m (20 ft), but is remarkebly persistent and can be traced from the Ohio-Kentucky line north to Cuyahoga County. East from Cuyahoga County to the Ohio-Pennsylvania line, however, the Sunbury cannot be separated from the overlying Orangeville shale of the Cuyahoga Formation.

CUYAHOGA FORMATION

The Cuyahoga Formation is a thick rather complex sequence of shale, sandstone, and conglomerate. The unit takes its name from Cuyahoga County, where it was first described. The thickness of the unit differs; a maximum of about 190 m (625 ft) was reported in the Hocking Valley region by Hyde (1915, p. 670). The Henley shale, Buena Vista sandstone, and Portsmouth shale (ascending order) are significant members in southern Ohio. The higher Black Hand sandstone and Berne conglomerate members are widespread in the central part of the State. In northern Ohio, the unit is predominantly bluish-gray shale.

LOGAN FORMATION

The Logan Formation, which was named for the town in Hocking County, marks the top of the clastic part of the Mississippian sequence in Ohio. The Logan consists of sandstone, conglomerate, sandy shale, and shaly sand. The Byer sandstone, Allensville conglomerate, and Vinton sandstone (ascending order) are widely recognized members in the southern and south-central parts of the State. The Logan extends northward only to about Wayne County and is not present in northern or northeastern Ohio.

MAXVILLE LIMESTONE

The Maxville Limestone, named for the village in Perry County, is the only carbonate unit in the Mississippian section of Ohio. The unit is very discontinuous on the outcrop and only slightly more persistent in the subsurface. Morse (1910) recognized that the Maxville rested disconformably on the underlying Logan Formation; other workers have subsequently confirmed this fact. Uttley (1974) reviewed the existing data on the pre-Maxville disconformity and concluded that its relief was relatively low. The discontinuous nature of the Maxville is a reflection of dissection that took place between the close of Mississippian deposition and the beginning of Pennsylvanian deposition. Limestone is confined mainly to the area south of a line from Muskingum County to Belmont County. Maxville pebbles, however, are incorporated in basal Pennsylvanian rocks on the outcrop as far north as Wayne County, and Uttley (1974) reported a small area of limestone in Jefferson County. The thickness of the unit differs considerably, generally being less than 15 m (50 ft) on the outcrop and perhaps reaching as much as 59 m (195 ft) in the subsurface. These data clearly show that the Maxville once covered a much larger area and that the present distribution is the result of severe widespread post-Mississippian erosion.

The possibility has long been recognized that rocks correlated with Maxville represented more than one correlative stratigraphic and age unit. Uttley (1974), on the basis of a synthesis of available paleontological and stratigraphic data, suggested that the Maxville could be divided into units of formational rank and that it spans both Meramecian and Chesterian time. (See fig. 8.)

PENNSYLVANIAN

The Pennsylvanian rocks of Ohio are a repetitive sequence of lenticular sandstones, mudstones, freshwater and marine limestones, clays, and coals, averaging about 335 m (1,100 ft) in thickness. Rapid facies changes are the norm, and most beds do not have good lateral continuity. Because of the general lack of distinctive lithologic or faunal differences within any individual group, correlation must be made on the basis of gross lithologic characteristics and stratigraphic sequence.

Unlike the underlying Mississippian rocks, the Pennsylvanian rocks of Ohio thicken slightly to the southeast. Greatest thickness is along the Ohio River in Monroe and Washington Counties, where an increase in thickness of about 67 m (200 ft) more than the outcrop average is found. Basal Pennsylvanian units reach as high as the Massillon sandstone and rest directly on the Maxville Limestone, Logan Formation, or Cuyahoga Formation, depending on the depth of the pre-Pennsylvanian erosion.

Sandstone ranges from massive to shaly bedded and from very fine grained to coarse grained and conglomeratic. The mineralogic composition of several sandstone units in the Monongahela and Dunkard Groups ranges from 62 to 90 percent quartz, 2 to 21 percent clay and silt, 0.1 to 1 percent heavy minerals, 2 to 10 percent feldspar, 1 to 8 percent mica, and 1 to 9 percent rock fragments (Collins and Smith, 1977). The lowest sandstone of the Pottsville Group tends to be much cleaner and contains 98 to 99 percent quartz.

Mudstone units are prominent in the Conemaugh, Monongahela, and Dunkard Groups. Mudstone units are virtually nonbedded, break with an irregular fracture, are generally calcareous and have limy nodules, are semiplastic to nonplastic, and consist predominantly of clay- and silt-size particles. Mudstones are predominantly red or some shade of red, and green to greenish-gray mottling is common. Such units have been variously called clay-shale, shale, marl, and red beds.

Nonmarine limestones range from light to dark gray and are generally cryptocrystalline to very finely crystalline and homogeneous. They normally have a relatively high clay content and break down readily on weathering. Conglomeratic or brecciated nonmarine limestones, in which both matrix and pebbles are composed of similar material, are relatively common.

Marine limestones vary from black to medium greenish gray to light gray and are generally medium crystalline to coarsely crystalline. The beds range from relatively pure limestone (>90 percent $CaCO_3$) to calcareous shale. In some areas, the limestones of the Allegheny and Pottsville Groups grade into marine flints.

Clays are present under most coals and are generally illitic, noncalcareous, plastic to semiplastic, light to dark gray, nonbedded, and in many places bear root traces. In the Allegheny and Pottsville Groups, much of the clay is a kaolinitic nonplastic "flint" type.

Ohio's coal is of high-volatile bituminous rank, and, on an "as received" basis, ranges from about 5 to 20 percent ash, from 1 to 6 percent sulfur, and from 10,000 to 13,000 Btu (British thermal units). Coals overlain by marine shale and limestone tend to contain more sulfur than those overlain by nonmarine strata.

POTTSVILLE GROUP

The Pottsville is the basal group of the Pennsylvanian System in Ohio. The group averages 78 m (256 ft) in thickness on the outcrop and consists of thick conglomerates, sandstones, and shales, and of thin coals, marine limestones, and shales. Stout and others (1943, p. 140) estimated that sandstones constitute about 42 percent of the total thickness of the group. Very thin iron carbonate or clay ironstone beds are associated with many of the marine zones; although no longer of commercial interest, these "ores" were the basis for the historically important Hanging Rock iron district of southern Ohio and northern Kentucky. Nonmarine limestone is not known to be present in this group.

The named beds in the Pottsville of Ohio number 26 (table 4). The Sharon conglomerate, which is the lowest significant unit in the group, is very erratic in distribution, having been deposited in valleys cut in the underlying Mississippian. The Sharon is typically composed of clean medium to coarse quartz sand or pebbles. This unit's principal area of occurrence is Summit, Portage, Geauga, and adjacent counties in northern Ohio. The unit also is present in Jackson, Pike, and Scioto Counties to the south. The Sharon and the higher Massillon sandstone are both noted for high-purity silica; both units are economically important. The Sharon (No. 1) and Quakertown (No. 2) coals, which are associated with these units, also tend to be the Ohio coals lowest in sulfur.

Like the Sharon conglomerate, all beds from the base of the Pottsville to the Massillon sandstone were deposited on a rather deeply dissected Mississippian surface and, for that reason, are erratic in occurrence. Above the Massillon sandstone the sec-

TABLE 4.—*Generalized stratigraphic column for the Pottsville Group of Ohio*

Bed	Material
Homewood	Shale or sandstone.
Tionesta No. 3b	Coal, local.
Upper Mercer, Big Red Block	Ore, irregular
Upper Mercer	Limestone or flint.
Bedford	Coal, patchy.
Sand Block	Ore, siliceous, local.
Upper Mercer No. 3a	Coal, local.
Lower Mercer, Little Red Block	Ore, kidney.
Lower Mercer	Limestone, persistent, marine.
Middle Mercer	Coal, persistent, thin.
Flint Ridge	Coal, thin, local.
Boggs	Ore and limestone, marine.
Lower Mercer No. 3	Coal, persistent, thin.
Lowellville (Poverty Run)	Coal, thin, nonpersistent.
Vandusen	Limestone, or ore, marine.
Bear Run	Coal, local.
Massillon (Connoquenessing)	Shale or sandstone.
Quakertown No. 2	Coal, patchy.
Huckleberry	Coal, thin, local.
Guinea Fowl	Ore, local.
Anthony	Coal, thin.
Sciotoville	Clay, flint and plastic.
Sharon	Ore, local, marine.
Sharon No. 1	Coal, patchy.
Sharon	Conglomerate, patchy.
Harrison	Ore, local, impure.

tion becomes more regular, but, because of rapidly changing facies, individual beds are generally difficult to trace for great lateral distances.

ALLEGHENY GROUP

The Allegheny Group has 32 named beds (table 5) averaging about 65 m (212 ft) in thickness, and is similar in most respects to the underlying Pottsville Group. A major lithologic difference is the appearance of thin nonmarine limestone in the Allegheny Group. The Hamden limestone is the lowest freshwater limestone in the Pennsylvanian of Ohio and appears slightly above the Lower Kittanning (No. 5) coal. This group is of major economic importance in the State because of its large coal and clay resources and lesser, but important, limestone resources.

CONEMAUGH GROUP

The Conemaugh, containing 40 named beds (table 6), is the thickest of the four groups composing the Pennsylvanian section. The group averages 122 m (400 ft) on the outcrop. The Conemaugh is virtually devoid of major economically important coals. Thick sandstones, mudstones, and shales are abundant. Thin coals, freshwater and marine limestones, marine shales, and clays are also present. Above the Skelley limestone, the section becomes more continental, and marine units disappear from the section; *Lingula* specimens, however, are present in a very few localities at the position of the much higher Permian-age Washington coal. In general, the freshwater limestones become much thicker in the upper half of the group.

The first appearance of red coloration in this group indicates an important change in Pennsylvanian-age rocks. Red rocks are not present in the underlying Pottsville or Allegheny Groups. Red mudstones and thinner red shales become quite abundant from about the Anderson coal upward. The first occurrence of red strata, however, is normally at, or slightly above, the Upper Freeport coal. Thus, the appearance of red beds is quite useful as a general stratigraphic marker, particularly in the subsurface.

MONONGAHELA GROUP

The Monongahela Group, containing 25 named beds (table 7), averages 75 m (247 ft) in thickness

TABLE 5.—*Generalized stratigraphic column for the Allegheny Group of Ohio.*

Bed	Material
Upper Freeport No. 7	Coal, patchy.
Upper Freeport	Limestone and marly shale.
Bolivar	Coal, local, thin.
Bolivar	Clay, flint and plastic.
Upper Freeport	Shale or sandstone.
Dorr Run	Shale, marine, local.
Lower Freeport (Rogers)	Coal, patchy.
Lower Freeport	Limestone, local.
Lower Freeport	Shale or sandstone.
Upper Kittanning	Coal, seldom present.
Washingtonville (Yellow Kidney ore)	Shale, marine.
Middle Kittanning No. 6	Coal, persistent.
Leetonia	Limestone, local.
Red Kidney ore	Shale, siliceous.
Strasburg	Coal, local.
Oak Hill	Clay, flint and plastic.
Hamden	Limestone, nonpersistent.
Columbiana	Limestone, marine, local.
Lower Kittanning No. 5	Coal.
Lawrence	Coal, shaly, local.
Kittanning	Shale and sandstone.
Ferriferous	Ore, irregular.
Vanport	Limestone, marine.
Scrubgrass	Coal, seldom present.
Clarion No. 4a	Coal, patchy.
Canary	Ore, very local.
Clarion	Sandstone, irregular.
Winters	Coal, very local.
Zaleski	Flint, impure, marine.
Ogan	Coal, local.
Putnam Hill	Limestone, marine.
Brookville No. 4	Coal, persistent.

TABLE 6.—*Generalized stratigraphic column for the Conemaugh Group of Ohio*

Bed	Material
Upper Pittsburgh	Limestone, irregular.
Upper Little Pittsburgh	Coal, very local.
Bellaire	Sandstone, local.
Lower Little Pittsburgh	Coal, seldom present.
Summerfield (Lower Pittsburgh)	Limestone.
Connellsville	Sandstone, local.
Clarksburg	Coal, local.
Clarksburg	Limestone and marly shale.
Morgantown	Sandstone, local.
Elk Lick	Coal, usually wanting.
Elk Lick	Limestone and marly shale.
Birmingham	Shale, siliceous.
Skelley	Limestone, local, marine.
Duquesne	Coal, seldom evident.
Gaysport	Limestone, siliceous, marine.
Ames	Limestone, marine.
Ames	Coal, very local.
Harlem	Coal, persistent.
Rock Riffle	Limestone, very local.
Round Knob-Pittsburgh	Clay, calcareous.
Saltzburg	Sandstone, local.
Barton	Coal, local.
Ewing	Limestone, ferruginous.
Cow Run	Sandstone, local.
Portersville	Limestone, marine.
Anderson	Coal, persistent.
Bloomfield	Limestone, local.
Cambridge	Limestone, marine.
Wilgus	Coal, nonpersistent.
Buffalo	Shale or sandstone.
Upper Brush Creek	Limestone, marine.
Upper Brush Creek	Coal, local.
Lower Brush Creek	Limestone and shale, marine.
Lower Brush Creek	Coal, local.
Mason	Coal, local.
Upper Mahoning	Shale or sandstone.
Mahoning (Groff)	Coal.
Thornton	Clay, irregular.
Mahoning	Limestone, local.
Lower Mahoning	Shale or sandstone.

and, except for the presence of several commercially important coal beds, is very much like the upper half of the Conemaugh. Arkle (1959) described three facies in the Monongahela Group in the Appalachian basin. These facies in the Ohio part of the basin are: (1) a gray facies consisting of many alternating thin gray shale and limestone beds and thick coals in the northern and central part of the outcrop area, (2) a red facies consisting of thin variegated red and yellow mudstone and massive sandstone in the southeastern part of the State; coal is lacking or much thinner than that in the northern area, and (3) a transitional facies consisting of thin impure coals, limestones, and variegated red and yellow mudstones in central eastern Ohio tying together the northern and southern areas. As stated above, no marine units are known in the group.

DUNKARD GROUP

As presently interpreted, rocks assignable to the Dunkard Group span the Permian-Pennsylvanian boundary; for this reason these rocks are discussed both here and under the Permian. (See table 8 for stratigraphic column.) The Dunkard Group in Ohio averages 191 m (626 ft) in thickness on the outcrop and, as stated above, has traditionally been assigned to the Permian System. Presently, however, the rocks from the top of the Monongahela Group (Waynesburg coal) to the base of the Washington coal (lower Dunkard) are classified as Permian-Pennsylvanian in age. The rocks in this interval average 33 m (109 ft) and are indistinguishable from the underlying Monongahela Group. The age assignment for this part of the Dunkard is based not on lithology but rather on the waning of a typically Pennsylvanian flora and an increase of a Permian flora.

TABLE 7.—*Generalized stratigraphic column for the Monongahela Group of Ohio*

Bed	*Material*
Waynesburg No. 11	Coal, fair purity.
Gilboy	Shale and sandstone.
Little Waynesburg	Coal, persistent.
Waynesburg	Limestone and marly shale.
Uniontown	Shale or sandstone.
Uniontown No. 10	Coal.
Lower Uniontown	Coal, very local.
Uniontown	Shale, siliceous, and limestone.
Arnoldsburg	Sandstone.
Arnoldsburg	Coal, wanting.
Arnoldsburg	Limestone and calcareous shale.
Fulton	Shale, green, or shaly sandstone.
Benwood	Coal, very local.
Benwood	Limestone and calcareous shale.
Upper Sewickley	Sandstone, local.
Meigs Creek No. 9 (Sewickley)	Coal.
Lower Sewickley	Sandstone.
Fishpot	Coal, persistent, thin.
Fishpot	Limestone and marly shale.
Pomeroy (Fishpot)	Sandstone.
Pomeroy (Redstone)	Coal, nonpersistent.
Lower Meigs Creek (Lower Sewickley)	Coal, local.
Redstone	Limestone and marly shale.
Upper Pittsburgh	Sandstone, local.
Pittsburgh No. 8	Coal, persistent.

PERMIAN

Following U.S. Geological Survey usage, the Dunkard Group in Ohio traditionally has been divided into the Washington and Greene Formations The Washington averages 67 m (221 ft) in thickness and the Greene, 123 m (405 ft). No lithologic basis exists in Ohio for dividing the Dunkard into two formations and, unlike the underlying Pennsylvanian groups, neither is there a practical basis (table 8). The fact that undisputed *Callipteris conferta* specimens have not been found lower than the Washington coal (lower half of the Washington Formation) and the generally Permian character of the flora above the Washington coal form the basis for the current classification of these rocks. (See discussions of the Permian and Dunkard elsewhere in this paper.)

The following statement from Stauffer and Schroyer (1920, p. 15) provides an apt description of the Dunkard in Ohio:

> The Dunkard is a most variable series of rocks. There are sandstones, shales, beds of limestone, and coal; in fact it

TABLE 8.—*Generalized stratigraphic column for the Dunkard Group of Ohio*

Bed	*Material*
Gilmore	Sandstone.
Do.	Limestone, local.
Nineveh	Sandstone, local.
Do.	Coal, local, shaly.
Do.	Limestone, irregular.
Hostetter	Coal, thin, shaly, local.
Fish Creek	Coal, very local.
Do.	Sandstone, local.
Dunkard	Coal, local, impure.
Jollytown	Sandstone, local.
Jollytown 'A"	Coal, local, impure
Upper Washington	Shale, variable.
Hundred	Sandstone, local.
Upper Marietta	Sandstone.
Washington "A"	Coal, shaly, local.
Creston-Reds (Little Washington)	Limestone.
Lower Washington	Limestone.
Lower Marietta	Sandstone, local.
Washington	Coal, shaly.
Little Washington	Coal, shalv.
Mannington	Sandstone, local.
Waynesburg "A"	Coal, nonpersistent.
Waynesburg	Sandstone, rather steady.
Elm Grove	Limestone.
Cassville	Shale, gray.

includes nearly all the different varieties of sediments from coarse sandstone and conglomerate to the finest grained shale. These change rather rapidly from one to the other, so that it is often impossible to trace a horizon for any great distance. And then too, there is considerable similarity between a number of beds at different stratigraphic elevations. This is especially true of the shales which are often featureless and devoid of any marks whereby they may be recognized. Shale is the most abundant rock in the series. The higher shales are often red in the northern part of the area, while to the south red is the prevailing color of the shale throughout the whole series. Selenite crystals are occasionally to be found in these red shales. This is especially true in the vicinity of Marietta. Most of the limestones occur in the northern part of the area where the sandstones are but poorly developed. As the limestones are traced southward they pass into calcareous shales which are often full of nuggets of lime. Finally these disappear as do also nearly all traces of coal beds, and the series becomes one of chiefly shale and sandstone. These latter increase materially in importance in the southern part of the Dunkard field.

The shales referred to by Stauffer and Schroyer are, in fact, the mudstones (commonly called red beds) described in the lithostratigraphy section.

BIOSTRATIGRAPHY

The subdivisions used in the Carboniferous of Ohio are mainly rock-stratigraphic units and were established with little regard for time stratigraphy; this is especially true for the Pennsylvanian, where the classification is based largely on the relative abundance of minable coals. Age correlations have been made of the Carboniferous of the northern Appalachians, of the American midcontinent region, and of the European section (fig. 8).

The lower Mississippian in Ohio is age-correlated primarily on the basis of invertebrate macrofossils. Floral zones have been established for the Mississippian in the Eastern United States, but plants are far too rare in the Ohio section to be of value. The uppermost Mississippian (Maxville Limestone) has been correlated primarily on the basis of conodonts. The Pennsylvanian of Ohio has been correlated mainly on the basis of floral zones and fusulinids.

MISSISSIPPIAN

Although locally fossiliferous, the clastic units of the Mississippian in Ohio are not known for their abundant biota. Marine to brackish-water invertebrate faunas represent the most abundant group of fossils; vertebrate forms and plants are rare.

BEDFORD SHALE

In northern and central Ohio the Bedford Shale is fossiliferous in the basal few feet. This zone, at the contact with the underlying Cleveland shale (Devonian), yields abundant specimens of *Lingula* and *Orbiculoidea*. Mollusks, particularly bivalves, dominate the fauna of the soft gray shale and ironstone concretions of the basal few feet. The large spiriferid *Syringothyris bedfordensis* also is abundant in this zone.

Very little work has been done on the Bedford fauna since the reports of Herrick (1888a, b), Girty (1912), Cushing and others (1931), and Hyde (1953).

BEREA SANDSTONE

Very few fossils have been obtained from the Berea in Ohio. Rare fish remains have been reported: chondrichthyan dermal spines referred to *Ctenacanthus* (Newberry, 1889) and most notably well-preserved remains of the paleoniscoid *"Palaeoniscum" (Gonatodus) brainerdi.* Newberry reported numerous specimens from a now long-abandoned quarry at Chagrin Falls (eastern Cuyahoga County) (1873) and from Independence (south-central Cuyahoga County) (1889).

Plant remains, mostly carbonized fragments of *Annularia,* and poorly preserved brachiopods, including *Lingula melie* and *Trigonoglossa,* have been reported (Szmuc, 1970).

SUNBURY SHALE

The Sunbury Shale has yielded fish remains and a restricted invertebrate assemblage that includes the brachiopods *Lingula melie* and *Orbiculoidea herzeri,* sponge spicules, scolecodonts, conodonts, and foraminifers (Szmuc, 1957). Localities in northern Ohio have yielded well-preserved, although disarticulated, remains of the shark *Stethacanthus.*

CUYAHOGA FORMATION

Certain members of the Cuyahoga Formation are abundantly fossiliferous locally throughout the State. In northern Ohio, Szmuc (1957) reported the following generic diversity for the Cuyahoga macrofauna: brachiopods, 37; bivalves, 20; gastropods, 9; cephalopods, 4; sponges, 4; anthozoans, 2; bryozoans, 5; arthropods, 3. The most notably abundant and diverse macrofauna is that of the Meadville member in the Cuyahoga Valley, particularly in Medina County. Szmuc (1970) indicated that the Meadville member is the most fossiliferous unit in northeastern Ohio, and more than 125 species of invertebrates have been reported; most common are bryozoans and the brachiopods *Unispirifer* and *Ericiatia. Szmuc* (1970) summarized the paleontology of the remaining members of the Cuyahoga Formation in northern Ohio.

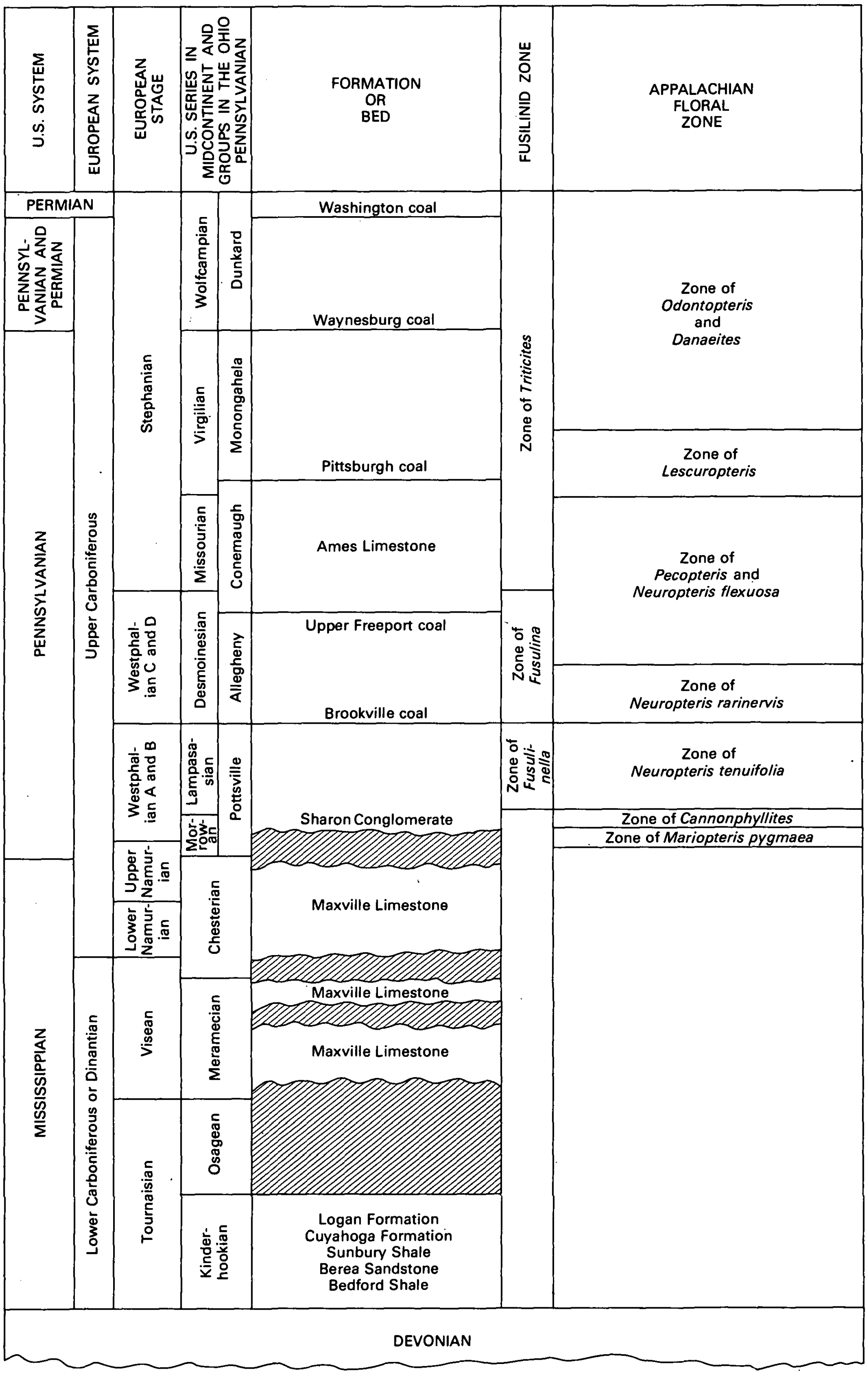

FIGURE 8.—Correlation chart showing the relationship of the Carboniferous section of Ohio to the European and U.S. midcontinent classification (modified from Moore and others, 1944; Weller and others, 1948; Dunbar and others, 1960).

The Cuyahoga fauna of central and southern Ohio has been reported upon most extensively by Hyde (1953), who listed numerous collecting localities. Manger (1971a) reported upon ammonoid cephalopods from the Cuyahoga of southern Ohio.

The most notable of the many collecting localities reported for the Cuyahoga Formation by Hyde (1953), is the Sciotoville Bar locality, a ledge along the northeast bank of the Ohio River in Scioto County, Ohio. This classic locality, from which Hyde obtained a large part of the fauna illustrated in the 1953 report, has been submerged since 1920 because of construction of a lock and dam. Manger (1971b) assigned the Sciotoville Bar locality to the upper part of the Portsmouth member.

LOGAN FORMATION

The fauna of the Logan Formation was described by Hyde (1953) and most comprehensively by Fagadau (1952). The clastic lithotope of the Logan Formation results in differing and, in some places, imperfect preservation of the macrofauna; however, Fagadau listed the following generic diversity of the Logan: bivalves, 22; brachiopods, 20; gastropods, 5; coelenterates, 5; ostracods, 2; trilobites, echinoderms, annelids, bryozoans, and scaphopods, 1 genus each.

Fagadau divided the Logan Formation into two faunal zones. The lower zone, which includes all strata below the Vinton member, is dominated by brachiopods, particularly *Rhipidomella missouriensis* var. *sulchella*, *Chonetes* cf. *C. pulchellus*, and *Spiriferina depressa*; however, the bivalve *Allorisma winchelli* and the gastropods *Tropidodiscus cyrtolites*, *"Worthenia" strigillata*, and *Platyceras haliotoides* are locally abundant. This lower zone of the Logan has faunal affinities with the underlying Cuyahoga Formation, as indicated by the mutual occurrence of 26 of the 62 species known from the Logan.

The upper zone of the Logan Formation, which includes the Vinton member, is dominated by brachiopods, of which *Dictyoclostus agmenes*, *Rhipidomella mesiolis*, and *Rhynchopora cooperensis* are the most important. *Composita* and *Pugnoides* make their first appearance in the middle part of this zone. Of the 25 species reported from the upper zone, 8 are present in the lower zone and 6 are known from the Cuyahoga Formation.

The Logan Formation is locally fossiliferous throughout its area of outcrop; however, the best collecting areas are in Licking, Fairfield, Ross and Scioto Counties. Fagadau (1952, p. 99) listed numerous localities, as did Hyde (1953).

MAXVILLE LIMESTONE

The macrofauna of the Maxville Limestone was studied by Morse (1910, 1911). Scatterday (1963) studied the conodont fauna, which serves as the principal basis for correlation of this unit. Of the 36 Maxville species listed by Morse (1910), 21 are mollusks; brachiopods, however are numerically dominant. Macrofossils are present throughout the Maxville, but they are most abundant, most easily obtained, and best preserved in the light-gray calcareous shale units. The massive sublithographic beds are seemingly less fossiliferous.

Numerous Maxville localities are listed by Morse (1910, 1911), Scatterday (1963), and Uttley (1974). A locality of particular note is the quarry Somerset Lime and Stone, Inc., west of Somerset in Hopewell Township, Perry County, Ohio.

PENNSYLVANIAN

The Pennsylvanian biota of Ohio has received considerable attention for more than a century, encouraged, in part, by the presence of economically valuable mineral deposits in these strata.

MARINE FAUNAS

Marine invertebrate faunas of the Pennsylvanian have been studied extensively, beginning in Ohio with the reports of the Ohio Geological Survey under the direction of J. S. Newberry (1869–1882). Smyth (1957) published on fusulinids, and Mark (1912) and Morningstar (1922) reported on the faunas of the Conemaugh and Pottsville Groups, respectively. More recently, Sturgeon and Hoare (1968) wrote the first monagraph on Pennsylvanian invertebrate groups in Ohio, a volume on brachiopods.

Sturgeon and Hoare (1968, p. 12), in reference to the brachiopod fauna, indicated that the Ohio fauna is slightly less diverse than that of the Western Interior basin; there are 42 genera and 93 species and varieties from the Ohio Pennsylvanian versus 46 genera and 130 species for the Western Interior basin. This reduced diversity for the Appalachian basin is probably evident in other faunal groups also. Multiple factors, including less favorable environments and physical barriers to migration into the Appalachian basin, are responsible for this reduction in diversity. In addition, an influential factor must be the absence of marine units in the upper Conemaugh and Monongahela Groups, which represent almost all the Virgilian sequence of the Western Interior basin (Sturgeon and Hoare, 1968, p. 13). Paleoecology of the Pennsylvanian marine faunas and environments have only recently received serious investigation. Principal investigators have been Donahue and Rollins (1974) and their students and Ferm (1970) and his students.

In Ohio, 28 marine horizons of Pennsylvanian age have been reported; only about 9 of these, however, can be considered important from the standpoint of yielding abundant and diverse faunas and of being widespread. The important units have produced faunas that include corals, bryozoans, fusulinids, arthropods, sponges, mollusks, and brachiopods. Generally, brachiopods are numerically dominant; however, the molluscan assemblage is more diverse. These units and faunas are most conveniently discussed by stratigraphic groups.

Pottsville Group.—Although 11 marine horizons have produced fossils in the Pottsville, the Lower and Upper Mercer limestones are most significant. Distinctive brachiopods in the Pottsville include *Cleiothyridina orbicularis* var. *crassalamellosa, Schizophoria resupinoides?, Rugosochonetes delicatus, Plicochonetes dotus, Desmoinesia muricatina* var. *missouriensis, Antiquatonia costellata, Juresania nebrascensis* var. *inflatia,* and *Krotovia paucispina* (Sturgeon and Hoare, 1968). Distinctive Pottsville fusulinids are *Fusulinella iowensis* and *F. stouti* (Smyth, 1957).

Allegheny Group.—Important marine units in the Allegheny Group are, in ascending order, Putnam Hill limestone, Vanport limestone, Columbiana shale, and Washingtonville shale. Diagnostic Allegheny brachiopods include *Composita girtyi, Wellerella tetrahedra, Mesolobus mesolobus, M. lioderma, Eolissochonetes fragilis, Chonetinella crassiradiata,* and *Reticulatia rugatia* (Sturgeon and Hoare, 1968). Distinctive fusulinids include *Wedekindellina euthysepta, Fusulina carmani, F. serotina,* and *F. leei* (Smyth, 1957).

Conemaugh Group.—The Brush Creek limestone, Cambridge limestone, and Ames limestone are the most important fossiliferous units in the Conemaugh. Distinctive brachiopods include *Derbyia parvicostata, Wellerella osagensis, Enteletes hemiplicatus, Orthotetes conemaughensis, Punctospirifer kentuckyensis* var. *amesi, Composita ohioense, C. magna, Neochonetes semiacanthus, N. granulifer, Chonetinella alata, C. flemingi, Hystriculina wabashensis, Pulchratia* cf. *P. ovalis, P. symmetrica* var. *regularis, Echinaria semipunctata, E. moorei, Antiquatonia portlockiana* var. *crassicostata, Reticulatia huecoensis, Juresania nebrascensis* var. *pulchra, Linoproductus* cf. *L. platyumbonus, L.* cf. *L. magnispinus,* and *L. oklahomae* (Sturgeon and Hoare, 1968). Distinctive Conemaugh fusulinids are *Triticites ohioensis, T. skinneri,* and *T. cullomensis* (Smyth, 1957).

Collecting localities.—Sturgeon and Hoare (1968) listed 346 localities from which they obtained 30,000 brachiopod specimens. Most of these localities have yielded a diverse assemblage of other invertebrate groups, and perhaps one-fourth have produced teeth or dermal spines of chondrichthyan fish. This locality register is the most comprehensive and up-to-date record available for marine Pennsylvanian fossils in Ohio.

NONMARINE FAUNAS (INCLUDING PERMIAN)

Nonmarine units yield faunas of bivalves, ostracodes, estherids, and vertebrates, including paleoniscoid and chondrichthyan fishes and, rarely, amphibians and reptiles. The nonmarine limestones yield diminutive molluscan faunas, but these units have never been collected systematically as have the marine horizons; therefore, their faunas are less well known. Eagar (1975) collected nonmarine bivalves from units in Ohio, discussed these faunas, and made comparison with other nonmarine faunas in North America and Europe.

Localities for nonmarine fossils are localized and less well known generally than are localities for marine units. Deserving of special mention, however, is the famous Linton vertebrate locality, at the mouth of Yellow Creek just south of Wellsville, section 7, Saline Township, Jefferson County, Ohio. A layer of cannel coal, several inches in thickness, at the base of the Upper Freeport coal (uppermost Allegheny Group), has produced remains of amphibians, paleoniscoid and chondrichthyan fishes, and phyllocarid crustaceans. This fauna has received considerable study by many authors, including Newberry (1873, 1875), Cope (1875), Romer (1930, 1963), Moodie (1909, 1915, 1916), Steen (1931), Baird (1964), and Westoll (1944). The mine dump of the long-abandoned Black Diamond mine still yields fossils to diligent collectors.

The Dunkard Group in Ohio has yielded fragmentary remains of amphibians, reptiles, freshwater chondrichthyans, paleoniscoids, and dipnoans. These remains must be considered rare, although the total of these specimens indicates a diverse "lake and pond" vertebrate fauna. Olson (1975) and Berman and Berman (1975) considered the fauna correlative to the classic Lower Permian Wichita and Clear Fork Groups of Texas. These authors and Lund (1975) recently summarized the Dunkard vertebrate fauna.

Vertebrate remains appear to be more abundant in the Washington Formation. Two localities are worthy of note. Moran (1952) reported the Cameron locality in section 18, Adams Township, Monroe County, Ohio, and Romer (1952) evaluated its fauna, which includes pleuracanth teeth, dipnoan remains, and the tetrapods *Eryops, Diploceraspis, Melanothyris,* and *Edaphosaurus,* among others. The Cameron locality yields fossils from a limestone and shale sequence about 2 to 3 m (7 to 10 ft) below the Waynesburg "A" coal. Olson (1970) summarized information on this locality.

The most productive vertebrate locality in the Dunkard Group of Ohio has been a localized channel conglomerate exposed near Belpre, Washington County. This deposit lies above the Upper Marietta sandstone near the top of the Washington Formation and has yielded a diverse, although fragmentary, vertebrate assemblage. Olson (1970, 1975) summarized the fauna of the Belpre locality; this fauna includes chondrichthyans, dipnonas, paleoniscoids, and the tetrapods *Eryops, Diploceraspis, Megamolgophus, Diadectes, Edaphosaurus,* and *Dimetrodon.*

An important nonmarine invertebrate occurrence in Belmont County is the presence of *Lingula permiana* in a shale parting of the Washington coal. This is the only known appearance in Ohio of a brackish-water form above the mid-Conemaugh Skelley limestone.

PLANTS (INCLUDING PERMIAN)

Plant impressions and compressions are abundant throughout the section, particularly in the shales overlying coals. The flora of the Pennsylvanian in the Appalachian basin was divided into several zones by Read (1947). The flora of Read's *Mariopteris pygmaea* zone (fig. 8) is found in the roof shale of the Sharon coal (Pottsville Group) in northeastern Ohio. Casts and molds of *Lepidodendron, Stigmaria,* and *Calamites* are common in sandstone, particularly that directly overlying coal. Petrifactions are less common, although some notable examples have been found. The Middle Branch of the Shade River in Lodi Township, Athens County, has long been famous for well-preserved (petrified) *Psaronius.* Hildreth (1838, p. 43) first described this general locality, and Andrews (1873, p. 287–288) placed the stratigraphic position in the lower part of the Monongahela (above the Pomeroy coal of Andrews); Andrews also used the term *Psaronius* in his text. Blickle (1940) and Morgan (1959) described *Psaronius* of the Shade River area in detail from the extensive collection of Blickle. Coal balls containing poorly preserved material have been known from Ohio for several years (Denton and others, 1961, p. 154); however, only recently did Rothwell (1976) and Good and Taylor (1974) describe well-preserved coal-ball floras from the middle Conemaugh and Monongahela Groups, respectively.

The first flora reported from Ohio and one of the earliest, if not the earliest, paleobotanical account in the United States was published in 1821 by Ebenezer Granger on plant impressions found in the uppermost part of the Pottsville Group at Zanesville, Muskingum County, Ohio. The material, which included *Neuropteris grangeri* Brongniart, was collected by Granger probably just below the Brookville coal at the Putnam Hill section on the west bank of the Muskingum River.

Another locality with a rich and interesting flora was described by Andrews (1875) from the lower part (7–9 m or 25–30 ft above the Maxville Limestone) of the Pottsville Group; the specimens were collected about 2 miles east of Rushville, Perry County, Ohio. Specimens identified and illustrated by Andrews included several species of *Megalopteris* and *Orthogoniopteris.* These localities, and many others, are listed and discussed by Stout (1945). Many other papers on Carboniferous floras are listed by Romans and McCann (1974).

ECONOMIC PRODUCTS

Carboniferous rocks in Ohio have been and continue to be a major source of valuable mineral resources. The Pennsylvanian is most noted for coal, but clay, sandstone, shale, and oil and gas (mostly in the past) have also made important contributions to the State's mineral wealth. Sandstone, oil and gas (mostly in the past), and shale have been the major resources produced from Mississippian rocks.

COAL

Coal is clearly the leading economic product of the Pennsylvanian System in Ohio and, in fact, is the most valuable mineral resource produced in the State. Coal beds assignable to the Monongahela Group (Upper Productive of early classifications) are the State's current major producing seams. Coals of the Allegheny Group (Lower Productive of early classifications) presently are second in total production. Coals of the Pottsville Group were formerly produced in Ohio, whereas mining of coal of the Conemaugh (Lower Barren of early classifications) has been of very minor importance. The Mississippian System in Ohio is not coal bearing.

From 1800, the first year of recorded production, to 1974, more than 2.7 billion tons of coal were mined in Ohio. The highest tonnage recorded for a single year was 55.1 million tons in 1970. The second highest year was 1918, when more than 47.9 million tons were mined. The character of the State's coal mining industry changed dramatically from 1918, when less than 2 million tons of coal was produced by open-pit methods, to 1970, when about 37 million tons of the record total was from open pits. Strip mining began in Ohio in 1914, but did not become important until World War II. From 1960 to 1970, strip mining increased and in 1970 accounted for more than 70 percent of the State's total production. In recent years, however, the percentage of the State's coal production from underground mining has been increasing slowly (Collins, 1976).

At the present time, the most productive seams are, in descending order of importance, Pittsburgh (No. 8), Meigs Creek (No. 9), Middle Kittanning (No. 6), Lower Freeport (No. 7A), and Waynesburg (No. 11). The Upper Freeport (No. 7), Lower Kittanning (No. 5), Quakertown (No. 2), and Sharon (No. 1) coals were formerly more extensively mined, but depletion of reserves, changes in mining methods, and economics have greatly reduced the importance of these seams.

Ohio's coals all fall into the high-volatile, bituminous rank and range from 5 to 20 percent ash, from 1 to 6 percent sulfur, and from 10,000 to 13,000 Btu. Low-sulfur coals, principally the Sharon and Quakertown, were formerly mined in Ohio, but most of the known reserves of these coals have been depleted. Most of the State's remaining resources fall into the medium (1.1 to 3.0 percent) to high (more than 3 percent) sulfur range.

On the basis of the latest resource tabulation of 46,488,251,000 tons (Brant and DeLong, 1960), less 5,395,442,000 tons mined and lost to mining and less 50 percent postulated to unavailability, 20,546,404,500 tons are left as Ohio's resource base. The resource base, however, includes coal not minable under current economic and technological conditions and, therefore, does not define the amount of coal that is presently available for production.

CLAY AND SHALE

Clay was formerly produced in considerably greater quantities than it is at present. Competition from concrete and plastics and from foreign pottery has made major inroads on Ohio's pottery and structural clay products industry. However, Ohio has traditionally led the Nation in the production of fireclays (coal underclays) and the production of structural clay products (such as sewer pipe, drain tile, and brick). Ohio is also a major producer of refractories.

Buff-burning clays particularly suitable for face brick are confined entirely to the Pennsylvanian System and primarily to the Pottsville and Allegheny Groups. The Allegheny Group is the principal clay-producing sequence of the State, primarily because of the Lower Kittanning clay. The Lower Kittanning, which immediately underlies the Lower Kittanning coal, is both the State's most widespread and most productive clay unit. This unit has been worked extensively for clay used in the manufacture of such products as refractories, sewer tile, building brick, wall and floor tile, and pottery; Lower Kittanning clay also has been used in cement for lightweight aggregate and as foundry bonding clay.

The Clarion, Oak Hill, Middle Kittanning, Lower Freeport, and Upper Freeport are other important clay units of the Allegheny Group. At the present time only the Clarion is being widely produced.

The clay resources of the Pottsville Group are the second most important in the State in production. The Tionesta and Brookville clays are worked rather extensively for use in the manufacture of face brick, sewer tile, wall tile, and refractories and are next in importance to the Lower Kittanning.

The clays of the Conemaugh and Monongahela Groups tend to be thin and discontinuous and are for the most part unsuited for ceramic use; these clays have been of little importance to the State's ceramic industry.

The Mississippian-age Bedford Shale and Logan Formation are worked in several localities in the State for clay used in the manufacture of face brick and tile. Pennsylvanian-age shale is sometimes blended with the clay to lower the firing range of the product.

SANDSTONE

Ohio is the largest producer of sandstone in the United States. Sandstone was one of the first mineral resources of the Carboniferous to be exploited by the early European settlers in Ohio (Stout, 1944). Sandstones useful for building stone, flagging, curb stone, decorative stone, refractories, grindstone, and pulpstone are abundant throughout the Carboniferous. In a few localities, upper Mississippian and lower Pennsylvanian sandstones are suitable sources of glass sands and silica pebble.

The use of sandstone as building stone has decreased substantially since the early 1900's owing to the use of cement block and brick. Grindstones have similarly lost favor to artificial abrasives. Even though many classical uses of sandstone have diminished over the years, other uses have been found, and production still remains relatively high. Present uses include dimension stone, aggregate, glass sand, metallurgical pebble, refractory linings, foundry sand, and riprap.

The principal sandstone units that have been developed in the Mississippian include units in the Bedford and Berea and units of the Cuyahoga, notably the Buena Vista and the Black Hand. Presently the Berea Sandstone in Lorain, Erie, and Huron Counties to the north and the Buena Vista member of the Cuyahoga Formation in Scioto County to the south are the principal producing units.

The Pennsylvanian System in Ohio contains many beds of sandstone about 6 to 12 m (20 to 40 ft) in thickness and several that locally thicken to as much as 31+ m (100+ ft). Many of these units have been exploited locally on a small scale. Two units, the Sharon conglomerate and Massillon sandstone, have been rather widely developed commercially and are the principal producing units at the present time.

OIL AND GAS

Carboniferous rocks have played a significant role in the development of the oil and gas industry in Ohio. Oil was known to exist in Ohio from the earliest days of statehood. A brine well drilled in 1814 in Noble County yielded large quantities of oil and gas (Hildreth, 1833, p. 64). Commercial development, however, did not start until 1859–60, when a gas well was developed in the Berea Sandstone at East Liverpool, Columbiana County. The success of the Drake well in western Pennsylvania in 1859 sparked drilling activity in several areas of eastern Ohio. Carboniferous rocks were the object of interest in these early exploration programs.

Oil was discovered in 1860 at Macksburg, Washington County, in stratigraphic units assignable to the Pennsylvanian-age Conemaugh Group and in Mecca Township, Trumbull County, in the Mississippian-age Berea Sandstone. By the late 1800's, oil and gas had been discovered also in the Mississippian-age Cuyahoga and Logan Formations and in the Pennsylvanian-age Pottsville and Allegheny Groups.

With the exception of the Berea Sandstone, extensive development of Carboniferous rocks in Ohio for oil and gas seems to be unlikely. The Berea, because of its much greater persistence and, in some areas, more uniform thickness, still offers opportunity for development.

LIMESTONE

The Maxville Limestone, as stated earlier, is the only carbonate unit in the Mississippian System of Ohio, and is the single most important limestone in the Carboniferous. The Maxville has been used for the manufacture of agricultural lime, quicklime, cement, road metal, railroad ballast, blast-furnace flux, and dimension stone. Presently, the unit is worked underground in Muskingum County for the manufacture of cement. Stone for riprap, road metal, concrete aggregate, and agricultural lime is quarried in the same area, as well as in Perry County. The Maxville formerly was deep-mined in Upper Township, Lawrence County, for cement stone.

Several Pennsylvanian-age marine limestones are commercially quarried: the Putnam Hill and Vanport limestones in the Allegheny Group and the Brush Creek and Cambridge limestones in the Conemaugh Group. The Vanport is the most extensively worked of these units. The bed is presently quarried for cement stone in Lawrence and Mahoning Counties and for riprap, road metal, and cement aggregate in Jackson, Lawrence, Mahoning, and Tuscarawas Counties. The unit is quarried for fluxstone in Mahoning County.

The Putnam Hill is worked for cement stone as well as for crushed stone in Stark County. The Brush Creek limestone is quarried for crushed stone in Athens County, and the Cambridge limestone is quarried for the same purpose in Guernsey County.

Freshwater limestones of the Conemaugh and Monongahela Groups are worked in a very small way for agricultural lime and for road metal. The Ewing limestone (Conemaugh Group) in Noble County, the Fishpot limestone (Monongahela Group) in Belmont and Harrison Counties, and the Benwood limestone (Monongahela Group) in Morgan and Washington Counties are the units presently being worked.

Other Pennsylvanian units have been worked on a minor scale. The thinness of the marine beds and the poor quality of the freshwater units are limiting factors in the use and development of these resources.

GROUND WATER

Ground water is not produced in prolific amounts from the Carboniferous rocks of Ohio, and major supplies must be obtained from surface waters. Units in the Pennsylvanian System throughout the State, with some notable exceptions, produce water at a general rate of 0.3 liters per second (5 gallons per minute) or less. Major exceptions are the Sharon and Massillon sandstones (Pottsville Group), which normally produce 2 to 6 liters per second (25 to 100 gallons per minute). Rare local exceptions do occur, and production of several hundred gallons per minute has been reported from Pennsylvanian units. Low ground-water yield is related to the fact that the Pennsylvanian section is to a large extent composed of impermeable shale and mudstone and sandstone which tend to have relatively low permeabilities.

Mississippian sandstone is generally somewhat cleaner, better sorted, and more permeable. Mississippian sands also tend to be somewhat more regular in distribution. Most of the region where water may be obtained from these sands will yield 0.3 to 2 liters per second (5 to 25 gallons per minute). As in the overlying Pennsylvanian, a unit rarely delivers several hundred gallons per minute.

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The Mississippian and Pennsylvanian (Carboniferous) Systems in the United States

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ON THE COVER

Swamp-forest landscape at time of coal formation: lepidodendrons (left), sigillarias (in the center), calamites, and cordaites (right), in addition to tree ferns and other ferns. Near the base of the largest *Lepidodendron* (left) is a large dragonfly (70-cm wingspread). (Reproduced from frontispiece in Kukuk, Paul (1938), "Geologie des Niederrheinisch-Westfälischen Steinkohlengebietes" by permission of Springer-Verlag, New York, Inc.)

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A. Massachusetts, Rhode Island, and Maine, by James W. Skehan, S.J., Daniel P. Murray, J. Christopher Hepburn, Marland P. Billings, Paul C. Lyons, and Robert G. Doyle

B. Pennsylvania and New York, by William E. Edmunds, Thomas M. Berg, William D. Sevon, Robert C. Piotrowski, Louis Heyman, and Lawrence V. Rickard

C. Virginia, by Kenneth J. Englund

D. West Virginia and Maryland, by Thomas Arkle, Jr., Dennis R. Beissell, Richard E. Larese, Edward B. Nuhfer, Douglas G. Patchen, Richard A. Smosna, William H. Gillespie, Richard Lund, Warren Norton, and Herman W. Pfefferkorn

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FOREWORD

The year 1979 is not only the Centennial of the U.S. Geological Survey—it is also the year for the quadrennial meeting of the International Congress on Carboniferous Stratigraphy and Geology, which meets in the United States for its ninth session. This session is the first time that the major international congress, first organized in 1927, has met outside Europe. For this reason it is particularly appropriate that the Carboniferous Congress closely consider the Mississippian and Pennsylvanian Systems; American usage of these terms does not conform with the more traditional European usage of the term "Carboniferous."

In the spring of 1976, shortly after accepting the invitation to meet in the United States, the Permanent Committee for the Congress requested that a summary of American Carboniferous geology be prepared. The Geological Survey had already prepared Professional Paper 853, "Paleotectonic Investigations of the Pennsylvanian System in the United States," and was preparing Professional Paper 1010, "Paleotectonic Investigations of the Mississippian System in the United States." These major works emphasize geologic structures and draw heavily on subsurface data. The Permanent Committee also hoped for a report that would emphasize surface outcrops and provide more information on historical development, economic products, and other matters not considered in detail in Professional Papers 853 and 1010.

Because the U.S. Geological Survey did not possess all the information necessary to prepare such a work, the Chief Geologist turned to the Association of American State Geologists. An enthusiastic agreement was reached that those States in which Mississippian or Pennsylvanian rocks are exposed would provide the requested summaries; each State Geologist would be responsible for the preparation of the chapter on his State. In some States, the State Geologist himself became the sole author or wrote in conjunction with his colleagues; in others, the work was done by those in academic or commercial fields. A few State Geologists invited individuals within the U.S. Geological Survey to prepare the summaries for their States.

Although the authors followed guidelines closely, a diversity in outlook and approach may be found among these papers, for each has its own unique geographic view. In general, the papers conform to U.S. Geological Survey format. Most geologists have given measurements in metric units, following current practice; several authors, however, have used both metric and inch-pound measurements in indicating thickness of strata, isopach intervals, and similar data.

This series of contributions differs from typical U.S. Geological Survey stratigraphic studies in that these manuscripts have not been examined by the Geologic Names Committee of the Survey. This committee is charged with insuring consistent usage of formational and other stratigraphic names in U.S. Geological Survey publications. Because the names in these papers on the Carboniferous are those used by the State agencies, it would have been inappropriate for the Geologic Names Committee to take any action.

The Geological Survey has had a long tradition of warm cooperation with the State geological agencies. Cooperative projects are well known and mutually appreciated. The Carboniferous Congress has provided yet another opportunity for State and Federal scientific cooperation. This series of reports has incorporated much new geologic information and for many years will aid man's wise utilization of the resources of the Earth.

H. William Menard
Director, U.S. Geological Survey

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