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

By HENRY H. GRAY

GEOLOGICAL SURVEY PROFESSIONAL PAPER 1110-K

Prepared in cooperation with the Indiana Geological Survey, Department of Natural Resources

Historical review and summary of areal, stratigraphic, structural, and economic geology of Mississippian and Pennsylvanian rocks in Indiana

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1979

CONTENTS

ILLUSTRATIONS

THE MISSISSIPPIAN AND PENNSYLVANIAN (CARBONIFEROUS) SYSTEMS IN THE UNITED STATES—INDIANA[1]

By HENRY H. GRAY[2]

ABSTRACT

Rocks of the Mississippian System are widespread in southwestern Indiana, where they reach a maximum exposed thickness of about 600 m. All parts of the period are represented, but the lowest series, the Kinderhookian, is very thin. Early Valmeyeran rocks consist of shale and siltstone; later Valmeyeran rocks are a sequence of limestone formations. Rocks of the Chesterian Series contain repeated alternations of limestone, sandstone, and shale.

The lower boundary of the Mississippian System is in a black shale sequence, is faunally determined, and has no physical expression. The upper boundary is a disconformity which has relief as great as 100 m. Mississippian rocks were uplifted, tilted, and erosionally beveled before deposition of Pennsylvanian sediments, so that Pennsylvanian rocks rest on youngest Mississippian rocks at the southern border of Indiana and on progressively older rocks northward.

Rocks of the Pennsylvanian System are widespread in southwestern Indiana, where they reach a maximum thickness of 500 m. Repeated cyclic sequences of sandstone, shale, coal, and limestone characterize the entire system, but subtle vertical distinctions may be perceived. In rocks of the Morrowan and Atokan Series, sandstone is the prominent rock type, and beds of coal are thin and local. The Desmoinesian Series, in which shale is dominant, contains five major commercial beds of coal. The Missourian Series also consists mainly of shale, but beds of coal are scattered and thin. Rocks of latest Pennsylvanian (Virgilian) age are not represented in Indiana.

INTRODUCTION

SOME BASIC FACTS

From the time of the first systematic geologic investigations in Indiana (Owen, 1838, 1839), it has been clear that rocks which in many other parts of the world are assigned to a single geologic system, the Carboniferous, here are divided into two lithologically distinct parts by a locally and regionally conspicuous unconformity. Classic study areas from which evolved the concept of the Mississippian System for the lower of these divisions are not far to the west; classic study areas from which evolved the concept of the Pennsylvanian System for the upper of these divisions are not far to the east. These two systemic terms have had increasingly common usage in Indiana for nearly 100 years, and they will be used in this report.

Rocks of the Pennsylvanian System underlie an area of nearly 19,000 km^2 in southwestern Indiana, or about one-fifth of the State's total area (fig. 1). The rocks constitute a dominantly clastic sequence of shale, siltstone, and sandstone, and intercalated thin but widespread beds of clay, coal, black shale, and limestone. Their maximum thickness is about 500 m near the southwest corner of the State; their mean thickness, however, is about half that figure, so that these rocks have a total volume of about 5,000 km^3. From these rocks is produced a large share of the State's mineral wealth. The total value of raw-mineral commodities produced from Pennsylvanian rocks in Indiana in 1976 was about $300 million (Indiana Geological Survey, 1977). Nearly all this value was derived from coal, which was mined mostly by stripping; of lesser value were oil, clay and shale, sandstone, and limestone.

Most of the area underlain by Pennsylvanian rocks is covered by residual soil or by younger unconsolidated deposits, which include till of Wisconsinan and Illinoian (late Pleistocene) ages and associated outwash sand and gravel, glacial lake silt and clay, loess, dune sand, and Holocene alluvium. Thickness of this cover is as much as 45 m in buried valleys near the confluence of the Wabash and Ohio Rivers, but over large areas the cover is less than a meter to a few meters thick. Scattered exposures of the bedrock are distributed throughout the area, but most of the larger exposures are found in the upland along the eastern margin of the outcrop belt and in strip mines that follow the crop line of the

[1] Published by permission of the State Geologist, Indiana Geological Survey, Department of Natural Resources, Bloomington, Ind. 47401.

[2] Head Stratigrapher, Indiana Geological Survey, Department of Natural Resources, Bloomington, Ind. 47401.

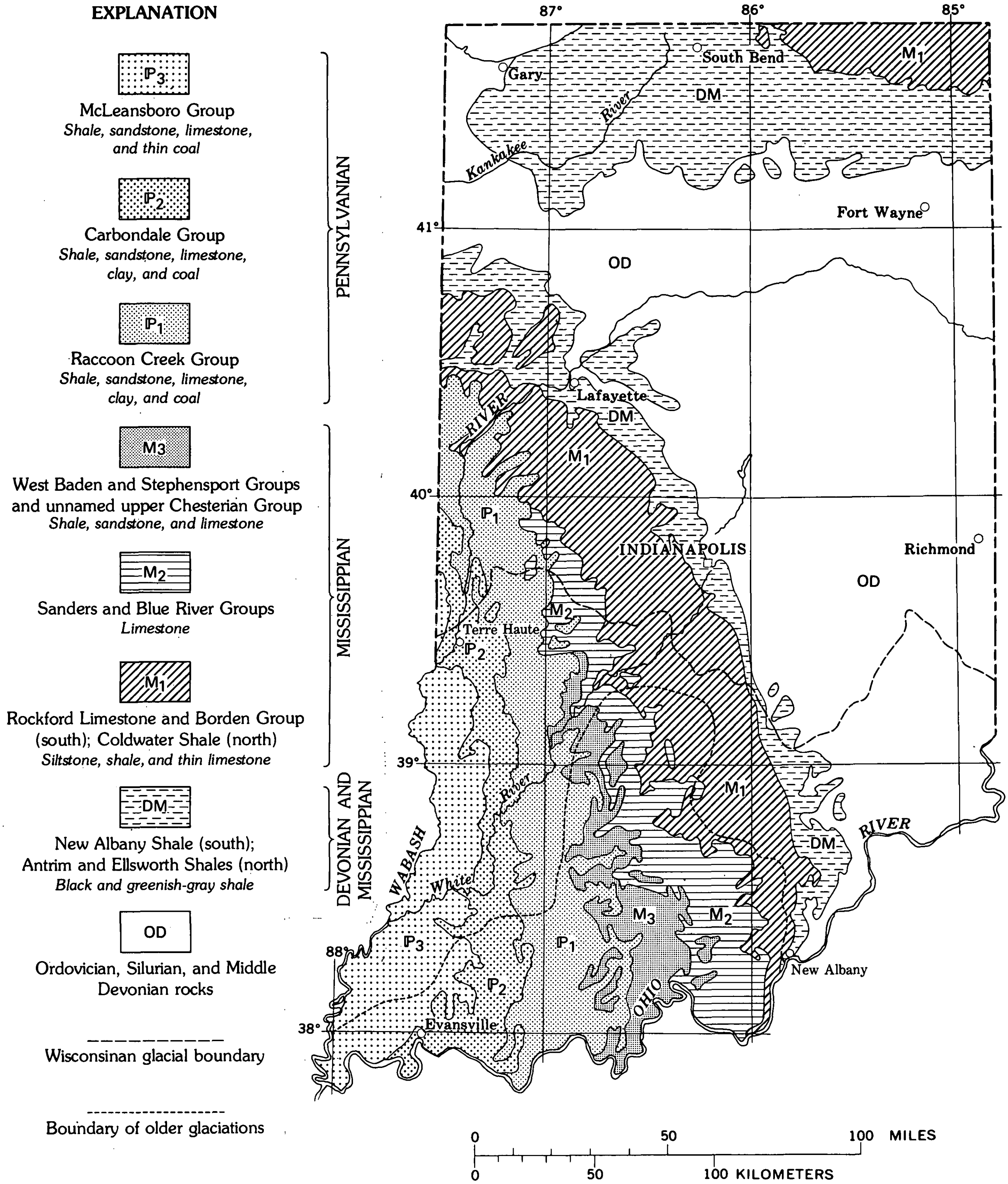


FIGURE 1.—Map of Indiana showing distribution of Mississippian and Pennsylvanian rocks.

major beds of coal in a north-northwest trend across the midsection of the belt.

The contact between rocks of the Pennsylvanian System and underlying rocks is a well-defined unconformity whose surface, as reconstructed from outcrop and subsurface data, has the aspect of a southwest-sloping plateau entrenched as much as 50 to 100 m by integrated systems of southwest-trending consequent stream valleys. Because of local relief on the unconformity, Pennsylvanian rocks in any given area may rest on several older formations, but a regional trend also exists because the older rocks were slightly tilted and erosionally beveled before deposition of basal Pennsylvanian sediments. As a result, Pennsylvanian rocks rest on youngest Mississippian rocks at the southern extremity of the outcrop area and on progressively older rocks northward. Along the main outcrop belt, the unconformity truncates almost the entire Mississippian System; in scattered outliers to the northeast, Pennsylvanian rocks lie on black shale of late Devonian age.

Rocks of the Mississippian System are at the bedrock surface in southwestern Indiana in an area of about 18,000 km^2 (fig. 1). They underlie Pennsylvanian rocks in the area previously described, and in northern Indiana they are at the bedrock surface in an additional area of nearly 4,000 km^2. Thus, in all they underlie slightly more than 40,000 km^2, or a little more than two-fifths of the State. These rocks are divisible into three lithologically distinct parts. The upper part, which comprises repeated cyclic sequences of sandstone, shale, and limestone, and the middle part, which consists principally of limestone of many textural varieties, are restricted to southwestern Indiana. The lower part, a clastic sequence of siltstone and shale, is present in both northern and southwestern Indiana.

In the southwestern outcrop area, Mississippian rocks are thickest near the Ohio River, where they attain a thickness of 600 m. They thin progressively northward, mainly as a result of the truncation earlier described, so that in west-central Indiana they are only about 100 m thick. In northernmost Indiana, their maximum thickness is about 200 m. The total volume of Mississippian rocks in Indiana is about 11,000 km^3, and the total value of raw-mineral commodities produced from these rocks in 1976 was about $60 million (Indiana Geological Survey, 1977). Mississippian rocks are the major source of oil in Indiana (Carpenter and others, 1975, p. 43). Also of importance are limestone (used principally for crushed stone, cement, and dimension stone), gypsum, shale, and sandstone.

In their northern area of occurrence (fig. 1), Mississippian rocks are entirely covered by glacial deposits; not a single exposure is known. Much of the southwestern area also is covered, although more thinly, by the same kinds of unconsolidated deposits that cover adjacent areas of Pennsylvanian rocks. In much of south-central Indiana, however, Mississippian rocks underlie only thin residual deposits and loess. Exposures thus are rather common, especially in large quarries in the limestone belt that trends northwestward from the Ohio River to central western Indiana.

Rocks in southwestern Indiana dip west-southwest at the rate of about 5 m/km away from the crest of the Cincinnati arch near the eastern border of the State and toward the axis of the Illinois basin. A few normal faults that have displacements as great as 60 m are known, mostly along the Wabash River near the southwest corner of the State. Rocks in northern Indiana dip northward at a similar rate toward the center of the Michigan basin.

HISTORY OF GEOLOGIC WORK AND EVOLUTION OF NOMENCLATURE

The history of geologic study of these rocks is long, and only a few of the works on which the present overview is based may be mentioned. Some of the important schemes of stratigraphic classification that have been used in this area are outlined in figures 2 and 3. Evolution of the nomenclature was discussed in detail by Cumings (1922), and more recently a brief review and an updating were presented in Shaver and others (1970).

Serious original research into Indiana geology began in 1837, when pioneer geologist David Dale Owen was appointed State Geologist and was instructed to make a 1-year survey that later was extended for an additional year (Owen, 1838, 1839). Owen's reports were printed many times; the most widely available version, which was considerably revised from earlier printings, is the 1859 printing (Owen, 1859a, b). Cumings (1922, p. 475) credited Owen as being the first geologist in American to recognize the twofold nature of the Carboniferous System, although, in a sense, Owen's classification was merely derived from the Mountain Limestone-Coal Measures scheme that had come into use in Europe, where Owen had been schooled. By 1859, Owen had refined and restated the definition of his "sub-carboniferous group" so that it almost exactly

Owen, 1859 a,b		Hopkins, 1904	Cumings, 1922; Logan, 1932	Current usage modified from Shaver and others, 1970: Group	Current usage modified from Shaver and others, 1970: Formation	Series	
Sub-carboniferous Group	Archimedes and Pentremital Limestones	Huron Limestone, Sandstone, and Shale	Negli Creek Limestone	——	——	Chesterian	Namurian
			——				
			Siberia				
			—— ——				
			Limestone				
			——				
			Tar Springs Sandstone		Tar Springs Formation		
			Glen Dean Limestone	Stephensport	Glen Dean Limestone		
			Hardinsburg Sandstone		Hardinsburg Formation		Visean
			Golconda Limestone		Haney Limestone		
			Indian Springs Shale		Big Clifty Formation		
			Cypress Sandstone				
			Beech Creek Limestone		Beech Creek Limestone		
			Elwren Formation	West Baden	Elwren Formation		
			Reelsville Limestone		Reelsville Limestone		
			Sample Sandstone		Sample Formation		
			Beaver Bend Limestone		Beaver Bend Limestone		
			Mooretown Sandstone		Bethel Formation		
	Barren Limestone	Mitchell Limestone	Paoli Limestone	Blue River	Paoli Limestone	Valmeyeran	
			Ste. Genevieve Limestone		Ste. Genevieve Limestone		
			St. Louis Limestone		St. Louis Limestone		
		Bedford Oolitic Limestone	Salem Limestone	Sanders	Salem Limestone		
		Harrodsburg Limestone	Harrodsburg Limestone		Harrodsburg Limestone		
					Ramp Creek Formation		Tournaisian
	Knobstone or Sub-carboniferous Sandstone	Knobstone Shale	Edwardsville Formation	Borden	Edwardsville Formation ——		
			Floyds Knob Formation				
			——		——		
			New Providence Formation		New Providence Shale		
	——	Rockford Goniatite Limestone	Rockford Limestone	——	Rockford Limestone	Kind.	
Black Bituminous Aluminous Slate		New Albany Shale	New Albany Shale		New Albany Shale	Chaut.	Fam.

FIGURE 2.—Evolution of Mississippian rock-unit nomenclature in southwestern Indiana. Minor boundary changes are not indicated. Units marked—either received no name or received names that have been shown to be not useful. Kind.=Kinderhookian, earliest Mississippian. Chaut.=Chautauquan, Fam.=Famennian, latest Devonian.

included what now constitutes the Mississippian System (fig. 2). He further recognized and described (Owen, 1859a, p. 20–23) a threefold lithologic division of the "sub-carboniferous group."

D. D. Owen embarked on another survey in 1859, but he died before the work was finished, and it was completed by his brother Richard (Owen, 1862). This report includes a section by Leo Lesquereux (1862) specifically describing the Coal Measures of Indiana. A few years later, a State geological survey was established as a continuing organization that has functioned, though the name has changed several times, until the present. Much of the research on the stratigraphy of Mississippian and Pennsylvanian rocks in Indiana has been done under the aegis of this organization.

In the early years, the Indiana Geological Survey concentrated on preparation of areal reports. In 1895, however, a new State Geologist, W. S. Blatchley, brought with him a "plan for taking up each of the great natural resources of the State" (Blatchley, 1897, p. 6). Backed by a corps of able assistants, many of whom later became nationally known, he produced a series of reports that remained definitive for many years. Worthy of mention in the present context are studies of the Carboniferous sandstones (Hopkins, 1896; Kindle, 1896), the famous dimension limestone (Hopkins and Siebenthal, 1897; Cumings and others, 1906), coal (Ashley, 1899, 1909), the lower Carboniferous (Ashley and Kindle, 1903), and the first detailed geologic map of the State, toward which many of the earlier studies were directed (Hopkins, 1904). Also during this period, two folio reports on the coal-bearing area were prepared by the U.S. Geological Survey to add to the then rapidly expanding Geologic Atlas of the

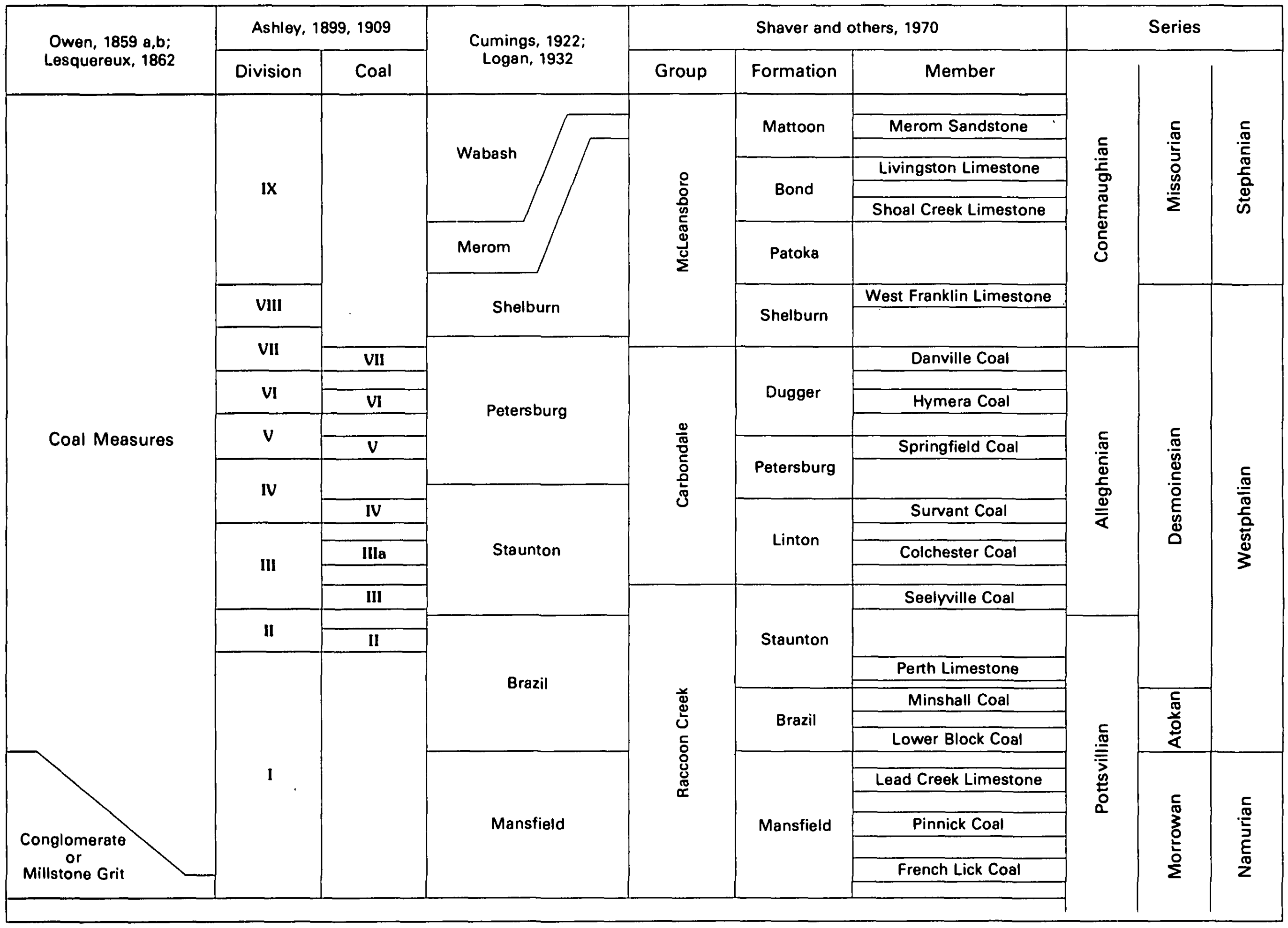


FIGURE 3.—Evolution of Pennsylvanian rock-unit nomenclature in Indiana.

United States (Fuller and Ashley, 1902; Fuller and Clapp, 1904).

The impetus of the Blatchley organization was not maintained, however, and the focus of geologic research shifted to Indiana University. Perhaps because the Ashley reports on coal were so thorough, faculty and students turned their attention mainly to the Mississippian rocks. Notable among these studies were those of Malott (1915, 1919, 1925, 1952) and Stockdale (1931, 1939). The present era of activity in the study of Indiana geology began when C. F. Deiss became State Geologist in 1946. In addition to renewed emphasis on mapping (Perry and Smith, 1958; Melhorn and Smith, 1959; Gray and others, 1960; Hutchison, 1960, 1976; Sunderman, 1968), interest has been extended into the vast store of subsurface data (Pinsak, 1957; Sullivan, 1972), and a series of Coal Investigations Maps has been prepared in cooperation with the U.S. Geological Survey (Friedman, 1961; Hutchison, 1958; Kottlowski, 1954, 1959, 1960; Waddell, 1954; Wier, 1950, 1951, 1954a).

The current definitive statewide geologic maps of Indiana consist of a series of Regional Geologic Maps published by the Indiana Geological Survey with the cooperation of geologists in adjacent States. Each of these maps covers an area of 1° in latitude by 2° in longitude and shows both bedrock and unconsolidated deposits on a scale of 1:250,000 Principal areas of outcropping Mississippian and Pennsylvanian rocks are shown on the Danville (Wayne, Johnson, and Keller, 1966), Indianapolis (Wier and Gray, (1961), Vincennes (Gray, Wayne, and Wier, 1970), and Louisville (Gray, 1972) quadrangles.

GEOLOGIC SETTING

Indiana lies astride the northwestward extension of the Cincinnati arch, a broad, gentle structural rise that divides the basins adjoining on the north, east, and west. Mississippian rocks in the Michigan basin are no closer to their Illinois basin counterparts than 150 km; Pennsylvanian rocks are separated by twice that distance. The early Paleozoic history of this structural feature is elusive, but by mid-Paleozoic time an arch in this general geographic position clearly was influencing sedimentation. In the late Paleozoic, this feature dominated the paleogeographic and paleotectonic patterns. During Mississippian and Pennsylvanian time, an arch separated the Michigan and Illinois basins so effectively that their depositional histories are quite distinct. Since the Pennsylvanian, these areas have been relatively stable tectonically so that the present structure fairly adequately portrays the tectonic framework that influenced late Paleozoic sedimentation.

In southwestern Indiana, the Devonian-Mississippian transition is placed near the top of a black shale, the New Albany Shale (fig. 2; Lineback, 1970, fig. 16). In northern Indiana, the transition is near the top of the Ellsworth Shale, which itself is transitional from the underlying black Antrim Shale to the overlying greenish-gray Coldwater Shale. Thus, the close of the Devonian Period is not marked by any obvious tectonic event in this area—yet there was a change in the character of the sediment, from black mud indicative of stagnant bottom conditions to greenish-gray mud that represents more oxygenated bottom conditions; this change marks the beginning of a prograding deltaic sequence that in turn reflect uplift of a source area far to the north and east. During earliest Mississippian time, however, the sedimentation rate remained exceedingly slow, so that the entire Kinderhookian Epoch is represented by scarcely more than a meter of shale and limestone (fig. 4).

Early in Valmeyeran time, a great delta composed mainly of silt was built along the eastern margin of the Illinois basin, but the prograding deltaic wedge failed to fill the basin. Carbonate-rock units not represented at the surface in Indiana succeeded the deltaic silt in deeper parts of the basin (Lineback, 1969), and it was not until middle Valmeyeran time that the deep basin was filled to overflowing. For the later half of Valmeyeran time, normal shelf-type shallow-water carbonate sedimentation was dominant.

A strong terrigenous influence again prevailed as the Chesterian Epoch began. Clastic materials poured into the Illinois basin from the northeast (Potter and others, 1958, Swann, 1964). These sediments appear to have bypassed the Michigan basin, which may have been full to the brim at the time. Vaccilating shorelines, deltas, and shallow seas are recorded by the deposits, in which terrigenous clastic and indigenous carbonate deposits alternate to form a pattern that has been called rhythmic (Swann, 1964). Clearly, at this time an approximate balance had been achieved between the rates of sedimentation and of subsidence. At the very end of Mississippian time or during earliest Pennsylvanian, the recently deposited sediments were slightly uplifted and tilted gently toward the west. Erosion shaped the newly emergent land into a surface of gently rolling uplands that here and there were rather sharply entrenched by consequent streams.

As the Illinois basin subsided slightly, deposition once more began about middle Morrowan time (fig. 5). A cyclic sedimentation pattern again is evident, but sediments are more continental than before; thus, few sediments represent offshore marine conditions and more are typical of deltaic and fluvial conditions (Wanless and others, 1970). Notable, though volumetrically minor, are deposits associated with coal-swamp environments. Beds of coal, underclay, and black roof shale are distributed throughout the Pennsylvanian rocks of Indiana, but the principal beds of coal are of Desmoinesian age.

Rocks of the Pennsylvanian System constitute the youngest bedrock in Indiana. Permian rocks have not been identified in the Illinois basin; Cretaceous rocks are known in southern and western Illinois (Willman and others, 1975, p. 205–206) but have not been found in Indiana. Some scattered occurrences of chert gravel are provisionally assigned to the Miocene or Pliocene (Lafayette Gravel, Shaver and others, 1970, p. 86–87; Luce Gravel, Ray, 1965, p. 17–21), but the geologic materials that overlie Pennsylvanian rocks in most areas are glacially related deposits of late Pleistocene age.

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 Indiana Geological Survey.

ACKNOWLEDGMENTS

Among the many colleagues to whom I am grateful for critical review and assistance in preparing this report are C. H. Ault, D. D. Carr, A. S. Horowitz, H. C. Hutchinson, R. L. Powell, C. B. Rexroad, R. H. Shaver, and C. E. Wier.

THE DEVONIAN-MISSISSIPPIAN BOUNDARY AND EARLIEST MISSISSIPPIAN ROCKS

In southern and western Indiana, the Devonian-Mississippian boundary is recognized within and near the top of the New Albany Shale (fig. 4). This formation consists predominantly of brownish-black partly dolomitic shale that contains as much as 20 percent by weight organic matter. Greenish-gray shale and mudstone that contain very little organic matter make up a lesser part of the formation. Rather uniformly about 35 m thick in the outcrop belt (fig. 1), the New Albany Shale thickens westward in the subsurface (Lineback, 1970).

Deposition of the Albany Shale began late in middle Devonian time and ended in middle Kinderhookian (early Mississippian) time. Conodont assemblages representative of two of the six zones of the standard upper Devonian sequence of Germany (Zones toI and toIII) are recognized in the lower and middle parts of the New Albany Shale, and assemblages indicative of early Mississippian age (Zones cuI and cuII) are known from the uppermost 0.5 m of the formation. From this and other faunal evidence, the Devonian-Mississippian boundary in southern Indiana can be placed about 0.6 to 1.8 m below the top of the New Albany Shale, but the boundary has no physical expression and cannot be more precisely located because definitive faunas do not occur at critical stratigraphic positions (Lineback, 1970, p. 39).

In northernmost Indiana, rocks equivalent to the New Albany Shale include the Antrim Shale, a brownish-black shale that is much like the New Albany, and the overlying Ellsworth Shale, a greenish-gray shale that has a transitional zone of interbedded brownish-black and greenish-gray shale at the base. Together, these two formations are about 60 m thick near the margin of the Michigan basin. Because of the thick glacial cover, these rocks are nowhere exposed. Sparse subsurface data suggest that the upper part of the Ellsworth Shale can be traced eastward into rocks in Ohio that are assigned to the Bedford Shale and the Berea Sandstone, and therefore is Mississippian in age.

Earliest Mississippian rocks in southern Indiana constitute many thin named beds in the uppermost part of the New Albany Shale. These include, in ascending order, a 6-cm bed of phosphatic nodules, the Falling Run Bed; a 12-cm bed of greenish-gray shale, the Underwood Bed; a 25-cm bed of black fissile shale, the Henryville Bed; and a 12-cm bed of greenish-gray glauconitic mudstone, the Jacobs Chapel Bed (Lineback, 1970, p. 27–29). None of these units is geographically extensive, but they are of interest because of the shifting environments that they suggest and because of the rich and varied faunas that they contain. Included are conodonts, scolecodonts, bryozoans, crinoids, brachiopods, gastropods, pelecypods, arthropods, fish, plants, and associated ichnofossils. An especially diverse conodont fauna has been found in the Jacobs Chapel Bed (Rexroad, 1969). All faunas indicate a Kinderhookian age.

Overlying the New Albany Shale, and forming a distinctive marker bed that separates the New Albany from the Borden Group above, is the Rockford Limestone (fig. 4). This formation, which commonly is about a meter thick, is a greenish-gray micritic dolomite (Lineback, 1970, p. 35). It has a fairly abundant and varied conodont fauna from which a latest Kinderhookian to earliest Valmeyeran (Osagean) age has been determined (Rexroad and Scott, 1964), but possibly the most interesting elements in the otherwise sparse fauna are the several species of goniatites and nautiloids that have been known since the time of Verneuil (1847). Recent collections from sites in two widely separated areas have also been described (Gutschick and Treckman, 1957; Lineback, 1963).

The Rockford Limestone is overlain by the New Providence Shale (fig. 4). The contact is a disconformity of very low relief, so that in some places the Rockford is missing and the New Providence rests directly on uppermost parts of the New Albany Shale (Lineback, 1970, p. 35–37).

THE MISSISSIPPIAN SYSTEM

Earliest Mississippian rocks, which represent Kinderhookian and part of Valmeyeran time, are very thin and have for convenience been discussed in connection with the Devonian-Mississippian boundary. The greater thickness of the Mississippian System in Indiana comprises three nearly equal parts: a clastic sequence (Borden Group) that is Valmeyeran in age a carbonate rock sequence (Sanders and Blue River Groups) that is Valmeyeran and earliest Chesterian in age and a mixed clastic-carbonate cyclic sequence (West Baden and Stephensport Groups and an unnamed group) that is Chesterian in age (fig. 4).

BORDEN GROUP

The most comprehensive study of the Borden Group is that of Stockdale (1931) who identified

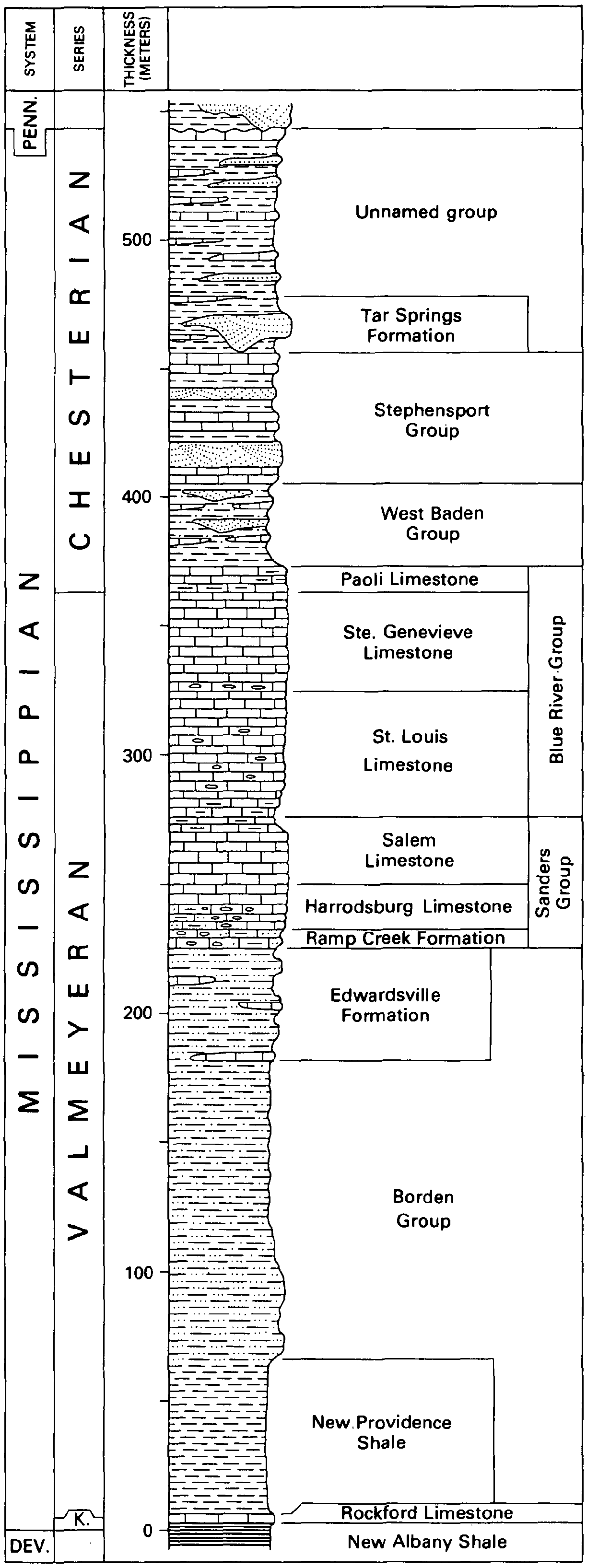


FIGURE 4.—Columnar section showing exposed Mississippian Rocks in Indiana. K.=Kinderhookian.

in the group five formations and a large number of lithic units that he designated facies and within which he recognized many members. Only a few of his names are still in use but his study remains a repository of factual data. The Borden Group represents a late and distal tongue of the great Catskill-Mauch Chunk delta system of the northern Appalachians but most of the sediment that was deposited in the Illinois basin probably had a northeastern source (Swann and others 1965).

The Borden Group comprises a rather straightforward prodelta-delta sequence. The green-gray and red-brown soft New Providence Shale represents the prodelta deposits; the overlying sequence of siltstones (fig. 4) varies from clay poor and sandstonelike to clay rich and shalelike and is regarded as deltaic. Kepferle (1977), in a recent study of a siltstone member in the lower part of the group, concluded that the siltstone is a turbidite that was deposited by west-southwest currents in relatively deep water at the base of a deltaic slope. Higher members of the group represent associated slope and platform deposits.

Toward the top of the Borden Group are a few thin and discontinuous beds of coarsely crinoidal limestone. In some places, similar rocks form small reefy masses as much as 3 km across and 20 m thick. These masses were referred to as bioherms by Stockdale (1931) in what was one of the earliest applications of the term. Bioherms near Crawfordsville have been known for many years because of the abundance and variety of crinoids and other fossils that they contain (Lane, 1973).

Maximum thickness of Borden rocks is about 250 m near the center of the State, which was an apparent major locus of sediment influx into the Illinois basin. The deltaic siltstone beds which constitute the greater part of the group, dip westward at a rate that is significantly greater than the true regional dip. In this way, the siltstones record initial dip of at least 3 m/km, which is consistent with an abrupt westward depositional thinning shown by the group. The Borden delta, therefore, is restricted to the margin of the basin; in the central part of the basin, only about 20 m of prodelta shale represents the Borden Group. This classic example of a sediment-starved basin, in which off-delta water depths may have reached 300 m, was documented by Lineback (1969), who also described the sequence of partial basin fills of successive limestone units that followed the close of Borden deposition.

The clay-poor siltstone beds of the Borden Group, particularly those in the upper part of the group, are resistant to erosion, so that the group is expressed physiographically as scenic uplands of considerable relief, thorough dissection, and steep slopes that have many exposures. Equivalent rocks in northern Indiana are referred to the Coldwater Shale, a greenish-gray slightly silty shale similar to the New Providence Shale. This formation is 150 m thick at the northeast corner of the State and is the youngest bedrock in the Indiana part of the Michigan basin.

SANDERS AND BLUE RIVER GROUPS

The mid-Mississippian limestone sequence—the "Barren Limestones" of Owen (1859a)—begins at the base with a complex succession of microrudites and biosparites that gradually give way upward to packstones and grainstones.[3]

These, in turn, are overlain by a thick series of micrites that in part are fossiliferous and pelletiferous. Low among the micrites are beds of gypsum, anhydrite, and micritic dolomite. Higher, some oolites appear, and toward the top of the sequence are thin beds of calcareous sandstone and siltstone that presage clastic depositional conditions to follow.

The Sanders Group (fig. 4) is at the base of this sequence and includes mainly coarsely textured types of limestone; some geode-bearing silty dolomite is interbedded near the base. This group ranges in exposed thickness from about 50 m near the Ohio River to a wedge edge in west-central Indiana (Nicoll and Rexroad, 1975). The thinning is partly depositional but ultimately is due to truncation beneath Pennsylvanian rocks. Downdip into the subsurface, the group thickens abruptly as a complement to the thinning of the underlying rocks that belong to the Borden delta. Thickness as great as 140 m has been recorded near the southwest corner of the State, where the group includes additional rock units that are not present at the outcrop.

At the top of the Sanders Group is the famous Salem Limestone. This formation is not, as is sometimes stated, an oolite; instead, it is a packstone to grainstone composed of sand-sized lime-coated fossil fragments. The prominent cross-stratification and lack of terrigenous detritus suggest deposition as a shallow shoal remote from shore (Carr and others, 1966). The texture and composition of this rock make it ideal for cutting and carving, and for many years it has been one of the premier building stones of the world (Rooney, 1970). Abundant among the microfauna of the Salem is the guide fossil *Endothyra (Globoendothyra) baileyi* (Hall), and in many places a diversified but diminutive megafauna is found. Especially notably is the Spergen Hill locality, which has been known for more than 100 years. Early monographic treatments of this fauna are those of Whitfield (1882) and Cumings and others (1906).

The Blue River Group (fig. 4) crops out from the southern boundary of the State, where the group is 150 m thick, northwestward about 200 km into west-central Indiana where it is truncated by the Mansfield Formation. In the subsurface the group is somewhat thicker. It consists mainly of micritic limestone, but oolite, sandy limestone (calcarenite), and chert of several types are prominent. Associated with gypsum and anhydrite in the lower part of the group are micritic dolomite and thin beds of black, gray, and green-gray shale. The evaporite deposits are economically important in the subsurface (French and Rooney, 1969), but they are poorly represented on the outcrop. In places in the northern part of the outcrop area, beds of limestone breccia occur at the evaporite position.

The gypsum-bearing rocks indirectly give rise to a group of mineral springs that center on French Lick and West Baden, towns that retain vestiges of the era when "taking the waters" was a popular pastime. Many other mineral spring localities are known, but the major sulfate water springs in Indiana lie nearly on a north-northwest line within about 40 km of French Lick. Along this line the gypsum beds lie at a depth of about 100 m. Gypsum and anhydrite are of wide extent downdip from the springs, but are thin and sporadic updip. The interface between the gypsum and the sulfate-water system is irregular and deeply embayed. Probably it is slowly progressing westward because of the constant removal of gypsum by solution.

In the upper part of the Blue River Group, true oolite is the subdominant lithology. As described by Carr (1973), this rock type commonly occurs as lenticular bodies about 2 km wide by 6 km long by 5 m thick. Inner parts of these bodies are composed of moderately porous grain-supported oolite; outer parts are of less porous oolite that is cemented by sparry calcite. Chemically, the rock is an exceedingly pure limestone that assays more than 98 percent calcium carbonate. In the subsurface, these oolitic

[3] Because no scheme of classification yet proposed is fully satisfactory for the wide variety of carbonate rock types in the Mississippian System of Indiana, selected terms from the classifications of Folk (1959) and Dunham (1962) have been used.

bodies are important reservoirs for petroleum; at the surface they are quarried for use as an industrial chemical. As modern analogs, Carr (1973) suggested the carbonate sand bodies of shallow marine shelf areas in the Bahamas banks.

WEST BADEN AND STEPHENSPORT GROUPS AND UNNAMED UPPER CHESTERIAN GROUP

Three groups in the upper part of the Mississippian System consist principally of terrigenous clastic rocks, and thus they are distinct from the underlying mid-Mississippian limestone sequence. The lowermost, the West Baden Group (fig .4), is about 35 m thick in the outcrop area (Gray and others, 1960). It consists of five formations, three of which are clastic and include sandstone, shale, siltstone, and mudstone, and two of which are biomicritic to oomicritic limestone. Near the base of the group in the Bethel Formation are beds of shaly coal as much as 5 cm thick, the oldest coal in Indiana.

Although the limestone formations of the West Baden Group are of normal marine origin, they are less continuous laterally than might be expected of such rocks. Gray and Perry (1956) found that in places the Reelsville Limestone is absent as the result of facies change. Hrabar and Potter (1969) and Sullivan (1972) related similar anomalies to the West Baden clastic belt, a branching, irregularly linear area 3 to 10 km wide that can be traced from the outcrop southwestward for about 80 km and in which the limestone formations are replaced laterally by sandstone and other clastic rocks. In a few places the transition is abrupt, but more commonly it is gradual and is accompanied by thickening of the limestone bed along with increasing content of noncarbonate material toward the clastic belt. Strips of sandy shale a kilometer or so in width normally separate the limestone bed laterally from the axial sandstone body.

The West Baden clastic belt is a distributary of Swann's (1963) Michigan River, an important feature of late Paleozoic geography. The belt marks the locus of virtually continuous clastic sedimentation that took place contemporaneously with deposition of the alternating clastic and carbonate rock units that typically are recognized in the West Baden Group. The limestone formations were deposited when the rate of clastic supply was regionally diminished, so that clastic deposition was limited to the distributary belt; the clastic formations represent times when terrigenous sediment was introduced in greater quantity and dispersed more widely. The geographic position of the clastic belt remained stable throughout West Baden time.

The Stephensport Group (fig. 4) is about 45 m thick in the outcrop area (Gray and others, 1960) and consists of five formations. The limestone formations, which are more continuous and more prominent in this group than in the West Baden Group, include biomicrite, oomicrite, biosparite, and oosparite. Among the abundant and varied faunas are pentremites (Galloway and Kaska, 1957), crinoids (Horowitz, 1965), bryozoans (Utgaard and Perry, 1960; Perry and Horowitz, 1963), and conodonts (Rexroad, 1958; Rexroad and Jarrell, 1961). The clastic formations consist of gray shale, siltstone, mudstone, and evenly stratified fine-grained sandstone. The sandstone beds also are more continuous than those of the West Baden Group and are notable cliff formers, so that the outcrop area of the Stephensport Group includes some of the most rugged terrain in southern Indiana.

The cyclic alterations of clastic- and limestone-dominated rock units that typify Chesterian deposition are best shown in the Stephensport Group. In general, the clastic units represent marine regressions and the limestone units represent transgressions. The Big Clifty Formation and the overlying Haney Limestone in the middle of the Stephensport Group make up such a regressive-transgressive couple. The lower two-thirds of the Big Clifty is an evenly stratified fine-grained sandstone of remarkable lateral extent along the outcrop (it is less continuous in the subsurface). It has a wavy upper contact that resembles megaripples and is succeeded upward in turn by thin marly mudstone, olive-gray and red-brown mudstone and shale, and gray shale that toward the top contains increasing numbers of fenestrate bryozoans and conularids. This sequence suggests a beach and barrier sand followed by a lagoonal mud that finally becomes fully marine. The biomicrites, biosparites, and oosparites of the overlying Haney Limestone represent a set of closely related shallow marine shelf and shoal environments (Vincent, 1975). Other comparable couples among the Chesterian rocks may be similarly, though not identically, interpreted.

Uppermost Chesterian rocks in southern Indiana have been described by Malott (1925) but have received no formal group name.[4] They are here con-

[4] After this paper was submitted for publication, these upper Chesterian rocks were described and their nomenclature was discussed in H. H. Gray, 1978, Buffalo Wallow Group—Upper Chesterian (Mississippian) of southern Indiana: Indiana Geol. Survey Occasional Paper 25, 28 p.

sidered an unnamed group that consists mainly of shale and that reaches a maximum thickness of 80 m near the Ohio River. About 70 km to the north, however, the group is truncated by the disconformity at the base of the Pennsylvanian System, so that areally this is the most restricted of the Mississippian groups.

This group consists predominantly of blue-gray, green-gray, and olive-gray shale and mudstone in which are interspersed a few beds of sandstone and many beds of limestone (fig. 4). Some of the limestone beds, which rarely are as much as a meter thick, represent tongues of much thicker limestone formations to the west. A thick and local sandstone member near the base of the group forms prominent cliffs and box canyons, but for the most part the group is topographically expressed as steep, smooth slopes beneath caprock ledges of Pennsylvanian-age sandstone. Formational terminology that is used for equivalent rocks in most of the Illinois basin (Swann, 1963) is not applicable here. For a discussion of some of the problems raised thereby, see Shaver and others (1970, p. 175–176).

Among the limestones of the unnamed group are thin beds of micritic dolomite that may indicate a sterile penesaline environment, but normal marine carbonate and shaly carbonate deposits containing bryozoan-brachiopod faunas that have not been studied are widely present. Conodont faunas of some of the limestones have been described by Rexroad and Nicoll (1965).

AGE AND CORRELATION OF MISSISSIPPIAN ROCKS

Many schemes have existed for the subdivision of Mississippian rocks by age; the Indiana Geological Survey follows the Illinois State Geological Survey in the usage (from oldest to youngest) of Kinderhookian, Valmeyeran (formerly Osagean and Meramecian), and Chesterian for epoch and series terms. The Kinderhookian-Valmeyeran boundary is about midway in the thin Rockford Limestone, as shown by conodont zonation (Rexroad and Scott, 1964). The Valmeyeran-Chesterian boundary is placed at the base of the Paoli Limestone (fig, 4), following the reasoning presented by Swann (1963, p. 17–20), who based his determination in part on the distribution of *Platycrinites penicillus*, a guide fossil found in the Ste. Genevieve Limestone, and *Talarocrinus*, which occurs in the Paoli Limestone and in younger Chesterian rocks.

Only a few paleontologic studies of Mississippian rocks in Indiana have attempted correlation with the European standard sections. Horowitz and Perry (1961) concluded, on the basic of crinoid faunas, that the Glen Dean Limestone probably is close to the Visean-Namurian boundary; from studies elsewhere, Mamet and Skipp (1971), on the basis of calcareous Foraminifera, would place this boundary between the Haney and Glen Dean Limestones. In parts of Europe, the Tournaisian-Visean boundary is placed within the zone of *Syringothyris*. In Indiana, this form is found in the Borden Group just below the Edwardsville Formation (Cumings, 1922, p. 493; Stockdale, 1931, p. 191), but on the basis of Mamet and Skipp's (1971) criteria, this boundary should be placed somewhat higher, probably at the base of the Harrodsburg Limestone.

THE MISSISSIPPIAN-PENNSYLVANIAN UNCONFORMITY

In the Midwestern United States, rocks of the Pennsylvanian System overlie older rocks at an unconformable contact that is second in regional importance only to the unconformity that separates Paleozoic from Precambrian rocks. In Indiana, this surface is a disconformity—that is, the uneven surface of contact is prominent but the strata above and below are virtually parallel. The crenelated line of outcrop of this disconformity trends from the Ohio River in a north-northwest direction some 300 km to west-central Indiana (fig. 1). The disconformity surface extends from this line southwestward across an area of nearly 19,000 km^2.

This disconformity has long been recognized as a buried ancient land surface that is mostly gently rolling, but that is entrenched, in some places quite deeply, by a set of subparallel valleys that trend southwestward entirely across the Illinois basin. The shape of this surface in part of Illinois was documented by Siever (1951). Similar documentation for Indiana does not exist, but Bristol and Howard (1971) prepared a so-called sub-Pennsylvanian paleogeologic map that covers much of the Illinois basin and that strikingly portrays the major valleys on the disconformity surface.

The full scope of the disconformity cannot be appreciated except through subsurface studies, but many aspects of it are well displayed on the outcrop. In a railroad cut near Shoals (Gray and others, 1957, p. 14–16), the disconformity is almost continuously exposed for nearly 300 m and clearly shows a small valley with relief of at least 20 m. Basal Pennsylvanian rocks here include sedimentary iron ore and sandstone, and rest on three formations of the Stephensport Group. Similar though less striking exposures may be observed at other places nearby (Gray and others, 1960, p. 29–35). In most places, however, the disconformity must be visualized on the basis of scattered data. For example, a valley about 35 m deep, 2 to 3 km wide, and more than 5 km long was mapped by Malott (1931), using only outcrop data. Quartz pebble conglomerate is an important part of the fill in this valley. Some of the deepest entrenchment is implied by isolated outliers 10 to 20 km from the main outcrop area (Malott, 1946). These outliers commonly are very porous sandstone, and where they rest on limestone they probably have been solutionally lowered, mostly during Cenozoic time, as has a sandstone channel-fill associated with the Bethel Formation in Kentucky (Indiana University, 1969).

North of the Wisconsinan drift boundary (fig. 1), the crop line of the Mississippian-Pennsylvanian disconformity is mostly covered, but there also the disconformity is a surface of considerable relief (Esarey and others, 1950). The valleys of Sugar Creek, Raccoon Creek, and their tributaries, most of which have been superimposed from a late Wisconsinan (late Pleistocene) drift surface and so have created many young valleys having extensive rock exposures, show the disconformity well. On a very local scale, in walking up the beds of some of these creeks, one can cross and recross the Mississippian-Pennsylvanian contact every few steps. Exposures in Shades State Park and just downstream along Sugar Creek show basal sandstone of the Mansfield Formation in contact with the Harrodsburg Limestone and siltstone of the Borden Group. Fifteen kilometers downdip to the west is a small inlier of the St. Louis Limestone that represents a hill about 75 m high on the disconformity surface.

Also observable at the outcrop is the regional truncation of the Mississippian rocks by those of the basal Pennsylvanian. Youngest Mississippian rocks underlie the Pennsylvanian near the Ohio River, but northward the disconformity gradually slices through 400 m of section. In scattered outliers to the northeast of the north end of the main Pennsylvanian outcrop, the entire Mississippian column is missing, and Pennsylvanian rocks rest on the New Albany Shale.

Although the disconformity is a profound and striking feature wherever it is well exposed, many of the rocks of the two systems are not readily identifiable with one system or another on a lithologic basis alone. Coal of respectable thickness, sedimentary iron ore, and nonstratified gray mudstone and clay are indicative of the Pennsylvanian System and biomicrite, biosparite, and red-brown and green-gray shale and mudstone are indicative of the Mississippian, but the more common kinds of shale and sandstone of the two systems are less distinct. In many shales of Pennsylvanian age, however, micas, carbonaceous materials, carbonized plant impressions, and siderite nodules are somewhat abundant than in otherwise similar rocks of Mississippian age. Many Pennslyvanian sandstones are somewhat coarser grained and more micaceous, and contain more abundant plant molds than do most Mississippian sandstones. Quartz pebbles, which in places are scattered through the basal sandstone beds of the Pennsylvanian System, also are useful indicators. These and other criteria were discussed by Atherton and others (1960) and Gray (1962).

The fauna of the youngest Mississippian rocks in Indiana clearly indicates an age very close to the end of Mississippian time. Somewhat younger Chesterian rocks are known from southern Illinois (Swann, 1963, p. 42–45; Collinson, Rexroad, and Thompson, 1971, p. 387–388). In contrast, the oldest identified Pennsylvanian florule from Indiana is from beds about 30 m above the base of the system and is placed by Read and Mamay (1964, p. K6–7) at their Zone 4-Zone 5 transition, below which in the central Appalachians there is a considerable section of Pennsylvanian rocks. Thus, it appears that basal Pennslyvanian rocks in Indiana are somewhat to considerably younger than oldest known Pennsylvanian rocks, and that the greater part of the hiatus represented by the unconformity belongs to Pennsylvanian time.

THE PENNSYLVANIAN SYSTEM

Coal constitutes only about 1 percent of the Pennsylvanian System in Indiana, but its economic impact has caused it to dominate stratigraphic work on these rocks since the earliest days of geologic research. The three nearly equal parts into which the system may be divided, principally on the basis of coal content, are more subtle than those of the Mississippian, and geologists have not generally found it useful to erect a semiformal classification such as that once used in the northern Appalachians in which "productive" and "barren" measures alternate. Nevertheless, a "productive" part of the system, which is Desmoinesian in age and which includes the thickest and most extensive beds of coal and widespread beds of limestone as well, may rather readily be identified (fig. 5). Below this, in rocks of Morrowan and Atokan age, sandstone is somewhat more prominent than in the rest of the

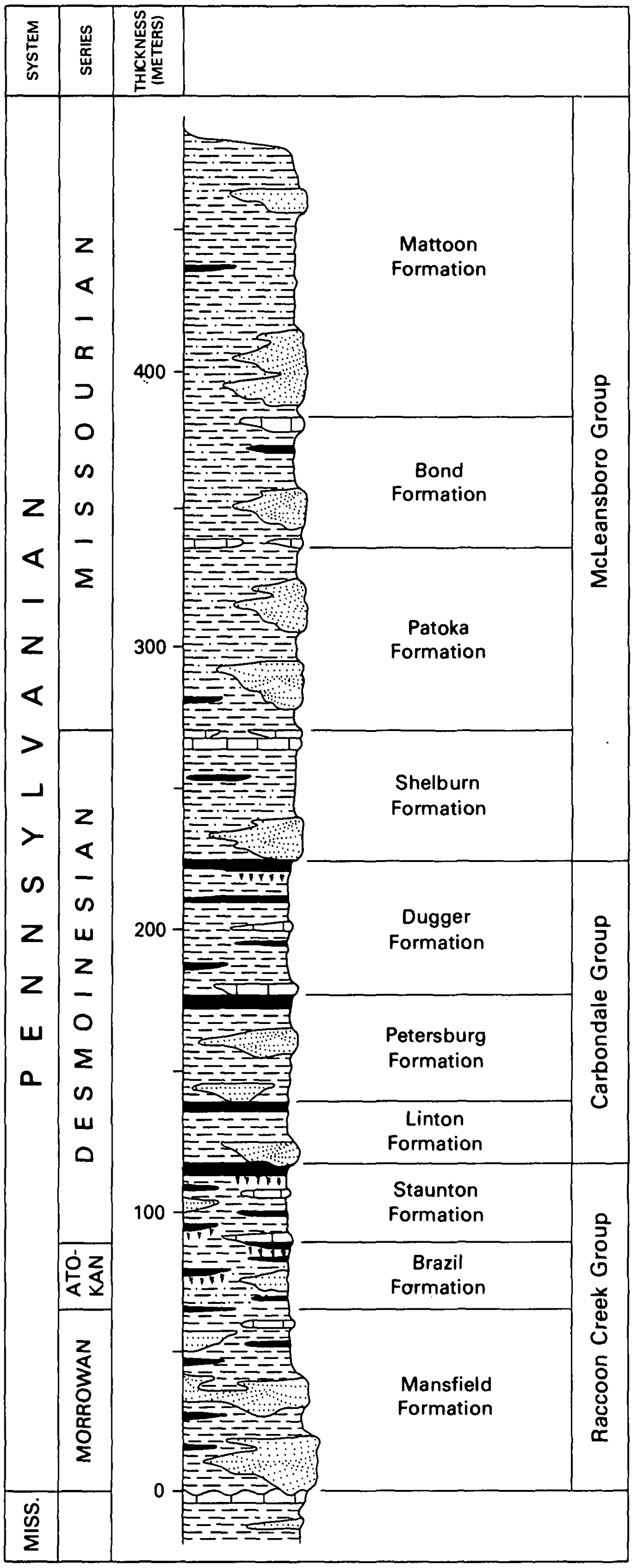


FIGURE 5.—Columnar section showing exposed Pennsylvanian rocks in Indiana.

system, and beds of coal and limestone are relatively thin and discontinuous. Above, in rocks of late Desmoinesian and Missourian age, shale is the dominant rock type, and only thin and local beds of coal and limestone are found. Rocks of latest Missourian and Virgilian age are not found in Indiana.

Formational nomenclature was slow to be applied to the Pennsylvanian rocks of Indiana (fig. 3), and even today is not applied strictly in accord with the precepts set forth in the Code of Stratigraphic Nomenclature, which calls for successive formations to be lithologically homogeneous and distinct one from another (American Commission, 1970, Art. 6). Contributing to this state of affairs are the following factors. First, by far the greater part of the Pennsylvanian System consists of a somewhat limited variety of common clastic rock-types—a few kinds each of sandstone, siltstone, shale, and clay. Truly distinctive lithologies are few. Second, the clastic rocks are interspersed with coal, limestone, chert, and sedimentary iron ore in repetitive cyclic sequences. Sequences that are seemingly identical may in fact be far apart stratigraphically. Third, lateral facies changes may be abrupt. Within short distances, individual beds and whole cyclic sequences may change in character so completely that they are scarcely recognizable. In consequence, formations in the Pennsylvanian System in Indiana are defined with reference to thin beds of coal and limestone used as key beds. As a further complication to traditional stratigraphic study, floral and faunal distributions are strongly facies controlled, so that fossil sequences that are effective for age determination or interregional correlation are sparse. These difficulties are shared with equivalent rocks both in the Appalachians, where the Pennsylvanian System has a more continental aspect, and in the midcontinent, where marine sequences are better developed.

RACCOON CREEK GROUP

Rocks that constitute approximately the lower one-quarter of the Pennsylvanian System in Indiana are assigned to the Racoon Creek Group (fig. 5). This group is extremely variable in thickness, primarily as a result of the disconformable relationship at its base. In the northern part of the outcrop area (fig. 1), the Raccoon Creek Group is 30 to 100 m thick (Hutchison, 1961); at the southern edge of the outcrop belt it is 150 to 200 m thick (Hutchison, 1959, 1971a); and in the subsurface at the southwest corner of the State, it is 300 m thick (Shaver and others, 1970, p. 137). Most of the increased thickness results from additional beds at the base of the group. Thus, beds in the lower part of the group in the southern outcrop area are not found to the north, and beds near the base of the group in the subsurface are not represented on the outcrop.

The lower part of the Raccoon Creek Group is designated the Mansfield Formation (fig. 5). Most of the variation in thickness shown by the group is assignable to this formation. As described from outcrop data (Gray, 1962), about 60 percent of the Mansfield Formation is sandstone, mostly evenly stratified to cross stratified; 22 percent is gray shale, and 14 percent is siltstone, mudstone, and clay. The rest includes small amounts of black shale, coal, limestone, chert, and sedimentary iron ore. Many of the sandstones are somewhat coarser grained and texturally less mature than those in the Mississippian formations. They contain significant, though small, amounts of clay as grain coatings, as matrix, and as discrete sand-size grains, some of which appear to be clots or aggregates and some of which probably are degraded shale fragments. Many of the sandstone beds are prominent cliff-formers, but most of the other rocks are less well exposed.

In the lower part of the Mansfield Formation near French Lick are beds of clay-bonded, slightly friable siltstone that are characterized by an exceptional smooth and uniform stratification. These rocks, which are used to make sharpening stones and are known as the Hindostan Whetstone Beds, cleave so perfectly that in quarrying they commonly are lifted out, by wedging, in sheets about 0.5 m wide by 2 m long by 2 cm thick. From their earliest use in 1821, some whetstones were exported to Europe (Carr and Hatfield, 1975, p. 11), but production now has almost ceased, and stratigraphic interest in the whetstones overshadows their economic value. Extending over an area of 20 km along strike by 5 km wide, in a zone about 15 m thick and marked above and below by thin but traceable beds of coal (Gray and others, 1960, p. 24–27), this unique lithology long has invited environmental interpretation as a lacustrine, lagoonal, or flood-plain deposit. In addition to the varvelike stratification, evidence includes a variety of delicate tracks and trails (Owen, 1859b, p. 17; Gray, 1962, p. 14), an assemblage of fossil plants (Kindle, 1896, p. 354–355), and large standing stumps of *Lepidodendron* (Kindle, 1896, p. 349–350).

Maps and other regional interpretations by Wanless (1955; 1975, p. 75) imply that the Hindostan Whetstone Beds constitute an isolated unit that is older than any other Pennsylvanian deposit in the Illinois basin. Although these beds contain a flora that apparently is older than any other Pennsylvanian flora yet studied in the basin, the beds are not an isolated occurrence. Rocks stratigraphically equivalent to the whetstone and to the marker beds of coal above and below have been traced northward for a few kilometers to where they are terminated by a facies change, and southward about 60 km to the Ohio River (Gray, 1962, p. 31). In the subsurface, where equivalent beds have been widely recognized (Hutchison, 1964, 1967, 1971b), they are underlain by 40 m or more of Pennsylvanian rocks. Included among these older rocks are a few beds of coal. The floras of this part of the Pennsylvanian System have not been studied, and probably among them are floras as old as the flora of the Hindostan Whetstone Beds, or older.

The principal producing beds of coal in the Raccoon Creek Group are those of the Brazil and Staunton Formations (fig. 5). Although local in extent and commonly no more than a meter thick, these have been mined by both underground and stripping methods. The Lower and Upper Block Coal Members of the Brazil Formation are of special interest. These are nonagglomerating and low in sulfur content, and their ash has a high fusion point. These properties placed them in demand for blacksmithing from the time of their discovery, about 1850. By 1870, the Block coals were being used as a direct charge in six Indiana blast furnaces, but by 1895 the last of these had ceased operation (Wayne, 1970) and these coals were then relegated mainly to domestic use. Also in the Brazil Formation, a waxy cuticular "paper coal" has been reported (Neavel and Guennel, 1960).

Many of the coal beds in the Staunton Formation are associated with marine deposits and characteristically have a relatively high sulfur content (Wier, 1973, fig. 9). The bed that marks the top of this formation and of the Raccoon Creek Group, the Seelyville Coal Member (fig. 5), is the lowest of the five most continuous and most productive beds of coal in Indiana.

CARBONDALE GROUP

Four of the five most productive beds of coal in Indiana are included in the Carbondale Group (fig. 5). Along the outcrop this group does not vary much from its average thickness of about 100 m, although the three formations that make up the group are themselves quite variable. These formations are, in ascending order, the Linton, Petersburg, and Dugger Formations. Each is bounded at the top by a widespread and thick bed of coal that is stratigraphically defined as a member (fig. 3). A few of the less extensive beds that are of stratigraphic importance also are defined as members.

The Carbondale Group extends across southwestern Indiana from the Ohio River north-northwestward to the Illinois State line just north of Terre Haute (fig. 1). This belt of outcrop fairly well defines the area of intensive strip mining (Powell, 1972); areas of underground mining lie within and west of the outcrop belt. Of the 1.3×10^9 metric tons of coal that has been produced in Indiana through 1970, nearly 90 percent has come from the Carbondale Group (Wier, 1973).

The Linton Formation ranges from 15 to 40 m in thickness, and averages about 25 m (fig. 5). This variation is due partly to sandstone lenses, which in places are as thick as 20 m, near the base of the formation. Closely overlying the sandstone, or overlying gray shale or clay where the sandstone is absent, is the Colchester Coal Member (fig. 3), a thin but widespread bed that is an important stratigraphic marker both in Illinois and in Indiana. Other major Indiana coals, notably the Seelyville and Survant Coal Members (fig. 3), are absent or are less well represented in Illinois.

Just above the Colchester Coal Member is one of two thin black shale beds that have been the object of probably the most intensive study of Pennsylvanian paleoenvironmental conditions in the Illnois basin. Zangerl and Richardson (1963), primarily in search of exquisitely preserved vertebrate remains (notably sharks), painstakingly excavated three sites, stratum by stratum. One of these sites was in the black shale overlying the Colchester Coal Member; the other two were in an older black shale in the Staunton Formation. These authors perceived the black shale environment as mainly shallow-water lagoonal, influenced by adjacent delta and shoreline sedimentation, and toxic, not as much a result of salinity variations (from marine to brackish to fresh) as it was a result of the presence of a flotant, a floating mat of vegetation that inhibited wave action and that contributed to anaerobic conditions in the water beneath it. The varied faunas appear to be death assemblages; animals floated or swam from more favorable environments associated with open water west of the studied sites into the restricted environments, where they died. Decay was slight and burial was swift.

The Petersburg Formation (fig. 5) is 25 to 50 m thick and averages about 35 m. It consists principally of shale and sandstone and includes at its top the Springfield Coal Member, from which for many years has come about half of the coal produced in Indiana (Wier, 1973, p. 28). Commonly, this member is 1 to 2 m thick, but it attains 4 m in one small area (Shaver and others, 1970, p. 170). Like most Indiana coals, it is bright-banded high-volatile bituminous coal. Its heating value on an as-received basis typically is about 6,400 calories per gram, and its ash content is about 10 percent. Because its average sulfur content is just over 3 percent (Wier, 1973, p. 14), recent exploratory effort has been directed toward defining areas of lower sulfur. The Springfield Coal Member commonly has a marine shale roof, but where the roof rock is nonmarine, the sulfur content of the coal is relatively low. Coal balls from this member contain beautifully preserved plant materials (Benninghoff, 1943); some also contain a marine invertebrate fauna (Boneham, 1976).

The Dugger Formation (fig. 5), which ranges from 25 to 50 m and averages 40 m in thickness, includes four named limestone members and four named coal members (Shaver and others, 1970, p. 49). The Alum Cave Limestone Member near the base of the formation is a widely traceable marine marker bed, but the other limestones appear to be of limited areal extent. Near the middle of the formation are two thin coal members, one of which probably is equivalent to the Herrin Coal, a principal mined coal in Illinois; neither of these beds is presently commercial in Indiana, however. The Hymera and Danville Coal Members in the upper part of the formation are widely recognized in the northern part of the Indiana coalfield and are thought to be equivalent to two beds, locally called the Lower and Upper Millersburg Coals, in the southern part of the field (Shaver and others, 1970, p. 41–42, 74–75). The correlation is uncertain because continuity of the beds is interrupted by a belt of clastic sediments that probably is contemporaneous with coal deposition. Some of the underlying beds, notably the Springfield Coal Member, also are discontinuous in the same area, and thus the clastic belt may represent a persistent route of sediment transport into the Illinois basin. The margins of the clastic belt are marked by splits, cutouts, and changes in the character of the coals.

McLEANSBORO GROUP

The upper part of the Pennsylvanian System in Indiana, constituting more than half of the system in rock thickness, has been something of an enigma to stratigraphers. The area of outcrop in southwestern Indiana is thickly loess covered, so that exposures are few and far apart; faulting and rapid southward thickening of the formations complicate geologic interpretation; and the rocks are not productive of coal or other economic minerals that would provide impetus for study. In earlier work, serious miscorrelations were made, notably in respect to the Merom Sandstone Member (fig. 3). The definitive study of these rocks is a doctoral dissertation (Wier, 1955) that has not been published, but conclusions from this study have been incorporated, with emendations as required by newer data, into the current "Compendium of Rock-Unit Stratigraphy in Indiana" (Shaver and others, 1970), and that volume is the basis for much of the discussion presented here.

All the rocks in the Pennsylvanian System above the top of the Danville Coal Member of the Dugger Formation are assigned to the McLeansboro Group (fig. 5), which consists, in ascending order, of the Shelburn, Patoka, Bond, and Mattoon Formations. The full thickness of the group in the central part of the Illinois basin is about 400 m, but in Indiana its maximum known thickness is 250 m.

The Shelburn Formation (fig. 5) is the most widely present and best known formation in the McLeansboro Group. It can be traced from near Evansville on the Ohio River to the Illinois State line a little north of Terre Haute (fig. 1). Its thickness ranges from 20 to 80 m and averages about 45 m. A thick sandstone member is present in places near its base; the rest of the formation consists principally of shale and siltstone and includes thin and discontinuous beds of coal. The West Franklin Limestone Member at the top of the formation is an important marker bed in Indiana and consists of one to three thin beds of limestone separated by shale. Total thickness of this member is about 5 m. In Illinois, according to Willman and others (1975, p. 167, 194), the West Franklin member is represented by three or more named members that span the lower half of the Modesto Formation.

The Patoka Formation is recognized in six counties in southwestern Indiana, but in most of this area it is the youngest Pennsylvanian formation and is not present in its full thickness. Where the entire formation is found, it is 30 to 50 m thick. Bounded at the bottom by the top of the West Franklin Limestone Member and at the top by the base of the Shoal Creek Limestone Member (fig. 3), the Patoka Formation consists principally of shale but includes several named sandstone, limestone, and coal members. Earlier miscorrelations of some of these members now have been corrected (Wier, 1955; Wier and Girdley, 1962). Most of these members are of limited areal extent; only one, the Inglefield Sandstone Member near the base of the formation, is recognized in Illinois (Willman and others, 1975, p. 196), where rocks equivalent to the Patoka Formation are assigned to the upper part of the Modesto Formation.

The Bond Formation (fig. 5) includes rocks between the base of the Shoal Creek Limestone Member and the top of the Livingston Limestone Member (fig. 3), both of which are important marker beds throughout much of the Illinois basin. This formation consists principally of shale and siltstone but includes one named sandstone member near its base and also contains one thin coal member and one limestone member. Because of faulting and erosion, the entire formation is present in Indiana in only two rather limited and widely separated areas. Its thickness is about 45 m (Shaver and others, 1970, p. 20). The formation has a wide distribution in Illinois, where many members are recognized that have not been identified in Indiana.

All Pennsylvanian rocks in Indiana above the top of the Livingston Limestone Member are assigned to the Mattoon Formation. Near the base of this formation is a prominent sandstone, the Merom Sandstone Member (fig. 3). Nearly all the thick sandstone members in the McLeansboro Group have at one time or another been identified as the Merom (see, for example, Malott, 1948); this member is now known to be present in Indiana only near the type locality in western Sullivan County and in the Mumford Hills area in northwestern Posey County (Wier, 1960; Shaver and others, 1970, p. 109). In the former area only about 12 m of the Mattoon Formation is present; in the latter area the formation reaches its maximum thickness in Indiana of about 45 m. These are the youngest Pennsylvanian rocks, and the youngest bedrock, in Indiana; somewhat younger rocks are present in Illinois where the Mattoon Formation reaches its maximum thickness of nearly 200 m near the center of the Illinois basin (Willman and others, 1975, p. 198).

AGE AND CORRELATION OF PENNSYLVANIAN ROCKS

Although plant megafossils have been reported from Pennsylvanian rocks in Indiana since the days of Owen (1859a, p. 43), few definitive studies have been made. Collections reported by Lesquereux (1880), C. D. White (in Kindle, 1896, p. 354–355), Jackson (1917), and Benninghoff (1943) constitute nearly all the earlier work. An overview by Canright 1959) summarized the earlier studies and briefly listed genera recognized from 93 collecting sites. In the most thorough study yet published, Wood (1963) reported 86 species in a single flora from the Brazil Formation; both late Pottsvillian and Alleghenian forms were included, however, and after extensive discussion of the distribution of many of the taxa elsewhere, Wood concluded (p. 28–30) that the flora cannot be used for precise age determination. Similarly, Read and Mamay (1964, p. K7) indicated that the flora of the Hindostan Whetstone Beds is transitional between their floral zones 4 and 5. Thus, the value of plant megafossils for precise age determination has not yet been established in the Pennsylvanian System of Indiana. Miospores from the coal beds were studied by Guennel (1952, 1958), who was convinced of their value in correlation, at least on a local basis, and who also suggested some regional correlations. He did not, however, attempt to design a zonal scheme or to assign standard age designations.

Whereas floral studies look eastward to the Appalachian area, faunal studies look westward to the midcontinent. Fifteen limestone members are named in the Pennsylvanian System of Indiana, and nearly all these contain marine invertebrate macrofossils or microfossils. Again, however, definitive studies are few, but some success in age determination and interregional correlation has been achieved through study of the microfauna of some of the older limestones. St. Jean (1957), on the basis of a foraminiferal faunule, established an early Desmoinesian age for a limestone in the Staunton Formation. Thompson and Shaver (1964), considering both fusulinids and ostracodes, suggested a correlation with type Morrowan rocks for several limestone beds in the upper part of the Mansfield Formation. Shaver and Smith (1974) confirmed both the above correlations and assigned the Brazil Formation, mostly by default of definitive faunas, to the Atokan Series. Microfossils from higher Pennsylvanian limestone beds have not been studied, but megafossils were listed by Wier (1955), who concluded (p. 64) that the West Franklin Limestone Member probably is latest Desmoinesian in age.

No definitive studies relating the Pennsylvanian rocks of Indiana to European standard sections have been made. The age assignments in European terms shown in figure 3 follow the provisional correlations presented by McKee (1975, p. 2).

REFERENCES CITED

American Commission on Stratigraphic Nomenclature, 1970, Code of stratigraphic nomenclature: Tulsa, Okla., Am. Assoc. Petroleum Geologists, 22 p.

Ashley, G. H., 1899, The coal deposits of Indiana: Indiana Dept. Geology and Nat. Resources, Ann. Rept. 23, p. 1–1573.

———1909, Supplementary report to the report of 1898 on the coal deposits of Indiana: Indiana Dept. Geology and Nat. Resources, Ann. Rept. 33, p. 13–150.

Ashley, G. H., and Kindle, E. M., 1903, The geology of the Lower Carboniferous area of southern Indiana: Indiana Dept. Geology and Nat. Resources, Ann. Rept. 27, p. 49–122.

Atherton, Elwood, and others, 1960, Differentiation of Caseyville (Pennsylvanian) and Chester (Mississippian) sediments in the Illinois basin: Illinois State Geol. Survey Circ. 306, 36 p.

Benninghoff, W. S., 1943, Preliminary report on a coal ball flora from Indiana: Indiana Acad. Sci. Proc., v. 52, p. 62–68.

Blatchley, W. S., 1897, Introductory: Indiana Dept. Geology and Nat. Resources, Ann. Rept. 21, p. 5–6.

Boneham, R. F., 1976, Marine invertebrate fossils in Pennsylvanian coal balls from southern Indiana: Indiana Acad. Sci Proc., v. 85, p. 78–88.

Bristol, H. M., and Howard, R. H., 1971, Paleogeologic map of the sub-Pennsylvanian Chesterian (Upper Mississippian) surface in the Illinois basin: Illinois State Geol. Survey Circ. 458, 14 p.

Canright, J. E., 1959, Fossil plants of Indiana: Indiana Geol. Survey Rept. Prog. 14, 45 p.

Carpenter, G. L., Dawson, T. A., and Keller, S. J., 1975, Petroleum industry in Indiana: Indiana Geol. Survey Bull. 42–N, 57 p.

Carr, D. D., 1973, Geometry and origin of oolite bodies in the Ste. Genevieve Limestone (Mississippian) in the Illinois basin: Indiana Geol. Survey Bull. 48, 81 p.

Carr, D. D., and others, 1966, Cross-bedding in the Salem Limestone of central Indiana: Sedimentology, v. 6, no. 2, p. 95–114.

Carr, D. D., and Hatfield, C. B., 1975, Dimension sandstone resources of Indiana: Indiana Geol. Survey Bull. 42–M, 28 p.

Collison, Charles, Rexroad, C. B., and Thompson, T. L., 1971, Conodont zonation of the North American Mississippian: Geol. Soc. American Mem. 127, p. 353–394.

Cummings, E. R., 1922, Nomenclature and description of the geological formations of Indiana, *in* Logan, W. N., and others, Handbook of Indiana geology: Indiana Dept. Conserv., Div. Geology, Pub. 21, pt. 4. p. 403–570.

Cumings, E. R., and others, 1906, Fauna of the Salem Limestone of Indiana: Indiana Dept. Geology and Nat. Resources, Ann. Rept. 30, p. 1187–1486.

Dunham, R. J., 1962, Classification of carbonate rocks according to depositional texture, *in* Ham, W. E., ed., Classification of carbonate rocks—a symposium: Tulsa, Okla., Am. Assoc. Petroleum Geologists Mem. 1, p. 108–121.

Esarey, R. E., Bieberman, D. F., and Bieberman, R. A., 1950 Stratigraphy along the Mississippian-Pennsylvanian unconformity of western Indiana: Indiana Geol. Survey Field Conf. Guidebook, 4, 23 p.

Folk, R. L., 1959, Practical petrographic classification of limestones: Am. Assoc. Petroleum Geologists Bull., v. 43, no. 1, p. 1–38.

French, R. R., and Rooney, L. F., 1969, Gypsum resources of Indiana: Indiana Geol. Survey Bull. 42–A, 34 p.

Friedman, S. A., 1961, Geology and coal deposits of the Terre Haute and Dennison Quadrangles, Vigo County, Indiana: U.S. Geol. Survey Coal Inv. Map C–44, scale 1:24,000.

Fuller, M. L., and Ashley, G. H., 1902, Description of the Ditney Quadrangle [Ind.]: U.S. Geol. Survey Geol. Atlas, Folio 84, 8 p.

Fuller, M. L., and Clapp, F. G., 1904, Description of the Patoka Quadrangle [Ind.-Ill.]: U.S. Geol. Survey Geol. Atlas, Folio 105, 12 p.

Galloway, J. J., and Kaska, H. V., 1957, Genus *Pentremites* and its species: Geol. Soc. America Mem. 69, 104 p.

Gray, H. H., 1962, Outcrop features of the Mansfield Formation in southwestern Indiana: Indiana Geol. Survey Rept. Prog. 26, 40 p.

———1972, Geologic map of the 1°×2° Louisville Quadrangle, Indiana, showing bedrock and unconsolidated deposits: Indiana Geol. Survey Regional Geol. Map 6.

Gray, H. H., Jenkins, R. D., and Weidman, R. M., 1960, Geology of the Huron area, south-central Indiana: Indiana Geol. Survey Bull. 20, 78 p.

Gray, H. H., and Perry, T. G., 1956, Local lithologic discontinuities in Reelsville (lower Chester) limestone of Indiana: Am. Assoc. Petroleum Geologists Bull., v. 40, no. 5, p. 1005–1009.

Gray, H. H., Wayne, W. J., and Wier, C. E., 1970, Geologic map of the 1°×2° Vincennes Quadrangle and parts of adjoining quadrangles, Indiana and Illinois, showing bedrock and unconsolidated deposits: Indiana Geol. Survey Regional Geol. Map 3, scale 1:250,000.

Gray, H. H., and others, 1957, Rocks associated with the Mississippian-Pennsylvanian unconformity in southwestern Indiana: Indiana Geol. Survey Field Conf. Guidebook 9, 42 p.

Guennel, G. K., 1952, Fossil spores of the Alleghenian coals in Indiana: Indiana Geol. Survey Rept. Progress 4, 40 p.

———1958, Miospore analysis of the Pottsville coals of Indiana: Indiana Geol. Survey Bull. 13, 101 p.

Gutschick, R. C., and Treckman, J. F., 1957, Lower Mississippian cephalopods from the Rockford Limestone of northern Indiana: Jour. Paleontology, v. 31, no. 6, p. 1148–1153.

Hopkins, T. C., 1896, The Carboniferous sandstones of western Indiana: Indiana Dept. Geology and Nat. Resources, Ann. Rept. 20, p. 186–327.

———1904, Geological map of Indiana: Indiana Dept. Geology and Nat. Resources, Ann. Rept. 28, scale 4 miles equals 1 inch.

Hopkins, T. C., and Siebenthal, C. E., 1897, The Bedford oolitic limestone: Indiana Dept. Geology and Nat. Resources, Ann. Rept. 21, p. 289–427.

Horowitz, A. S., 1965, Crinoids from the Glen Dean Limestone (middle Chester) of southern Indiana and Kentucky: Indiana Geol. Survey Bull. 34 52 p.

Horowitz, A. S., and Perry, T. G., 1961, Correlation with Great Britain of Glen Dean crinoid fauna (Chester, Mississippian) from Illinois Basin: Jour. Paleontology, v. 35, no. 4, p. 866–868.

Hraber, S. V., and Potter, P. E., 1969, Lower West Baden (Mississippian) sandstone body of Owen and Greene Counties, Indiana: Am. Assoc. Petroleum Geologists Bull., v. 53, no. 10, pt. 1, p. 2150–2160.

Hutchison, H. C., 1958, Geology and coal deposits of the Seelyville Quadrangle, Vigo County, Indiana: U.S. Geol. Survey Coal Inv. Map C–27, scale 1:24,000.

———1959, Distribution, structure, and mined areas of coals in Spencer County, Indiana: Indiana Geol. Survey Prelim. Coal Map 8.

———1960, Geology and coal deposits of the Brazil Quadrangle, Indiana: Indiana Geol. Survey Bull. 16, 50 p.

———1951, Distribution, structure, and mined areas of coals in Fountain and Warren Counties and the northernmost part of Vermillion County, Indiana: Indiana Geol. Survey Prelim. Coal Map 9, scale about 1 inch to 2 mi.

———1964, Distribution, structure, and mined areas of coals in Dubois County, Indiana: Indiana Geol. Survey Prelim. Coal Map 10, scale about 1 inch to 2 mi.

———1967, Distribution, structure, and mined areas of coals in Martin County, Indiana: Indiana Geol. Survey Prelim. Coal Map 11.

———1971a, Distribution, structure, and mined areas of coals in Perry County, Indiana: Indiana Geol. Survey Prelim. Coal Map 14.

———1971b, Distribution, structure, and mined areas of coals in Daviess County, Indiana: Indiana Geol. Survey Prelim. Coal Map 15.

———1976, Geology of the Catlin-Mansfield area, Parke and Putnam Counties, Indiana: Indiana Geol. Survey Bull. 54, 57 p.

Indiana Geological Survey, 1977, 100th Annual Report of the State Geologist: 38 p.

Indiana Univ., Cincinnati Univ. (Sedimentation Seminar), 1969, Bethel Sandstone (Mississippian) of western Kentucky and south central Indiana, a submarine-channel fill: Kentucky Geol. Survey, ser. 10, Rept. Inv. 11, 24 p.

Jackson, T. F., 1917, The description and stratigraphic relationships of fossil plants from the lower Pennsylvanian rocks of Indiana: Indiana Acad. Sci. Proc. for 1916, p. 405–428.

Kepferle, R. C., 1977, Stratigraphy, petrology, and depositional environment of the Kenwood Siltstone Member, Borden Formation (Mississippian), Kentucky and Indiana: U.S. Geol. Survey Prof. Paper 1007, 49 p.

Kindle, E. M., 1896, The whetstone and grindstone rocks of Indiana: Indiana Dept. Geology and Nat. Resources, Ann. Rept. 20, p. 328–368.

Kottlowski, F. E., 1954, Geology and coal deposits of the Dugger quadrangle, Sullivan, County, Indiana: U.S. Geol. Survey Coal Inv. Map C–11, scale 1:24,000.

———1959, Geology and coal deposits of the Coal City Quadrangle, Greene, Clay, and Owen Counties, Indiana: U.S. Geol. Survey Coal Inv. Map C–28, scale 1:24,000.

———1960, Geology and coal deposits of the Switz City quadrangle, Greene County, Indiana: U.S. Geol. Survey Coal Inv. Map C–41, scale 1:24,000.

Lane, N. G., 1973, Paleontology and paleoecology of the Crawfordsville fossil site (upper Osagian, Indiana): California Univ. Pubs. Geol. Sci., v. 99, 141 p.

Lesquereux, Leo, 1862, Report on the distribution of the geological strata in the Coal Measures of Indiana, *in* Owen, R. D., Report of the geological reconnoissance of Indiana: Indianapolis, H. H. Dodd and Co., p. 269–341.

———1880, Description of the coal flora of the Carboniferous Formation in Pennsylvanian and throughout the United States: Pennsylvania Geol. Survey, 2d, Prog. Rept. Paper, 977 p.

Lineback, J. A., 1963, Age of the Rockford cephalopod fauna (Mississippian) of southern Indiana: Jour. Paleontology, v. 37, no. 4, p. 939–942.

———1969, Illinois basin—sediment-starved during Missis-sipian: Am. Assoc. Petroleum Geologists Bull., v. 53, no. 1, p. 112–126.

———1970, Stratigraphy of the New Albany Shale in Indiana: Indiana Geol. Survey Bull. 44, 73 p.

Logan, W. N., 1932, Geological map of Indiana: Indiana Dept. Conserv., Div. Geology, Pub. 112.

McKee, E. D., 1975, Introduction, *in* McKee, E. D., and others, Paleotectonic investigations of the Pennsylvanian System in the United States: U.S. Geol. Survey Prof. Paper 853, pt. I, p. 1–7.

Malott, C. A., 1915, The Flatwoods region of Owen and Monroe Counties, Indiana: Indiana Acad. Sci. Proc. for 1914, p. 399–428.

———1919, The "American Bottoms" region of eastern Greene County, Indiana—A type unit in southern Indiana physiography: Indiana Univ. Studies, v. 6, no. 40, 61 p.

———1925, The upper Chester of Indiana: Indiana Acad. Sci. Proc., v. 34, p. 103–132.

———1931, Geologic structure in the Indian and Trinity Springs locality, Martin County, Indiana: Indiana Acad. Sci. Proc., v. 40, p. 217–231.

———1946, The Buddha outlier of the Mansfield Sandstone, Lawrence County, Indiana: Indiana Acad. Sci. Proc., v. 55, p. 96–101.

———1948, Geology of the Dicksburg Hills, Knox County, Indiana: Indiana Acad. Sci. Proc., v. 57, p. 125–141.

———1952, Stratigraphy of the Ste. Genevieve and Chester formations of southern Indiana: Ann Arbor, Mich., The Edwards Letter Shop, 105 p.

Mamet, B. L., and Skipp, B. A., 1971, Lower Carboniferous calcareous Foraminifera: Preliminary zonation and stratigraphic implications for the Mississippian of North America: Internat. Strat. Géol. Carbonifère, Cong., 6th, Sheffield 1967, Comptes rendus, v. 3, p. 1129–1146.

Melhorn, W. N., and Smith, N. M., 1959, The Mt. Carmel Fault and related structures in south-central Indiana: Indiana Geol. Survey Rept. Progress, no. 16, 29 p.

Neavel, R. C., and Guennel, G. K., 1960, Indiana paper coal—composition and deposition: Jour. Sed. Petrology, v. 30, no. 2, p. 241–248.

Nicoll, R. S., and Rexroad, C. B., 1975, Stratigraphy and conodont paleontology of the Sanders Group (Mississippian) in Indiana and adjacent Kentucky: Indiana Geol. Survey Bull. 51, 36 p.

Owen, D. D., 1838, Report of a geological reconnoissance of the State of Indiana, made in the year 1837 . . .: Indiana Senate Jour. for 1837–38, p. 126–157.

———1839, Second report of a geological survey of the State of Indiana, made in the year 1838 . . .: Indiana Senate Jour. for 1838–1839, p. 198–241.

———1859a, Report of a geological reconnoissance of the State of Indiana made in the year 1837 . . .: Indianapolis, Ind., John C. Walker, 63 p.

———1859b, Continuation of report of a geological reconnoissance of the State of Indiana, made in the year 1838 . . .: Indianapolis, Ind., John C. Walker, 69 p.

Owen, Richard, 1862, Report of a geological reconnoissance of Indiana: Indianapolis, Ind., H. H. Dodd and Co., 368 p.

Perry, T. G., and Horowitz, A. S., 1963, Bryozoans from the Glen Dean Limestone (middle Chester) of southern Indiana and Kentucky: Indiana Geol. Survey Bull. 26, 51 p.

Perry, T. G., and Smith, N. M., 1958, The Meramec-Chester and intra-Chester boundaries and associated strata in Indiana: Indiana Geol. Survey Bull. 12, 110 p.

Pinsak, A. P., 1957, Subsurface stratigraphy of the Salem Limestone and associated formations in Indiana: Indiana Geol. Survey Bull. 11, 62 p.

Potter, P. E., and others, 1958, Chester cross-bedding and sandstone trends in Illinois Basin: Am. Assoc. Petroleum Geologists Bull., v. 42, no. 5, p. 1013–1046.

Powell, R. L., 1972, Coal strip-mined land in Indiana: Indiana Geol. Survey Spec. Rept. 6, 18 p.

Ray, L. L., 1965, Geomorphology and Quaternary geology of the Owensboro Quadrangle, Indiana and Kentucky: U.S. Geol. Survey Prof. Paper 488, 72 p.

Read, C. B., and Mamay, S. H., 1964, Upper Paleozoic floral zones and floral provinces of the United States: U.S. Geol. Survey Prof. Paper 454–K, p. K1–K35.

Rexroad, C. B., 1958, Conodonts from the Glen Dean Formation (Chester) of the Illinois Basin [Ill.-Ind.-Ky.]: Illinois State Geol. Survey Rept. Inv. 209, 27 p.

———1969, Conodonts from the Jacobs Chapel Bed (Mississippian) of the New Albany Shale in southern Indiana: Indiana Geol. Survey Bull. 41, 55 p.

Rexroad, C. B., and Jarrell, M. K., 1961, Correlation by conodonts of Golconda Group (Chesterian) in Illinois Basin: Am. Assoc. Petroleum Geologists Bull., v. 45, no. 12, p. 2012–2017.

Rexroad, C. B., and Nicoll, R. S., 1965, Conodonts from the Menard Formation (Chester Series) of the Illinois basin: Indiana Geol. Survey Bull. 35, 28 p.

Rexroad, C. B., and Scott, A. J., 1964, Conodont zones in the Rockford Limestone and the lower part of the New Providence Shale (Mississippian) in Indiana: Indiana Geol. Survey Bull. 3$, 54 p.

Rooney, L. F., 1970, Dimension limestone resources of Indiana: Indiana Geol. Survey Bull. 42–C, 29 p.

St. Jean, Joseph, Jr., 1957, A Middle Pennsylvanian foraminiferal fauna from Dubois County, Indiana: Indiana Geol. Survey Bull. 10, 66 p.

Shaver, R. H., and Smith, S. G., 1974, Some Pennsylvanian Kirkbyacean ostracods of Indiana and midcontinent series terminology: Indiana Geol. Survey Rept. Prog. 31, 59 p.

Shaver, R. H., and others, 1970, Compendium of rock-unit stratigraphy in Indiana: Indiana Geol. Survey Bull. 43, 229 p.

Siever, Raymond, 1951, The Mississippian-Pennsylvanian unconformity in southern Illnois: Am. Assoc. Petroleum Geologists Bull., v. 35, no. 3, p. 542–581.

Stockdale, P. B., 1931, The Borden (Knobstone) rocks of southern Indiana: Indiana Dept. Conserv., Div. Geology, Pub. 98, 330 p.

———1939, Lower Mississippian rocks of the east-central interior [U.S.]: Geol. Soc. America Spec. Paper 22, 248 p.

Sullivan, D. M., 1972, Subsurface stratigraphy of the West Baden Group in Indiana: Indiana Geol. Survey Bull. 47, 31 p.

Sunderman, J. A., 1968, Geology and mineral resources of Washington County, Indiana: Indiana Geol. Survey Bull. 39, 90 p.

Swann, D. H., 1963, Classification of Genevievian and Chesterian (Late Mississippian) rocks of Illinois: Illinois State Geol. Survey Rept. Inv. 216, 91 p.

———1964, Late Mississippian rythmic sediments of Mississippi Valley: Am. Assoc. Petroleum Geologists Bull., v. 48, no. 5, p. 637–658.

Swann, D. H., Lineback, J. A., and Frund, Eugene, 1965, The Borden Siltstone (Mississippian) delta in southwestern Illinois: Illinois State Geol. Sûrvey Circ. 386, 20 p.

Thompson, M. L., and Shaver, R. H., 1964, Early Pennsylvanian microfaunas of the Illinois basin: Illinois Acad. Sci. Trans., v. 57, p. 3–23.

Utgaard, John, and Perry, T. G., 1960, Fenestrate bryozoans from the Glen Dean Limestone (middle Chester) of southern Indiana: Indiana Geol. Survey Bull. 19, 32 p.

Verneuil, E. de, 1847, Note sur le parallélisme des roches des dépôts paléozoiques de l'Amérique Septentrionale avec ceux de l'Europe . . .: Soc. Géol. France Bull. 4, ser. 2, p. 646–710.

Vincent, J. W., 1975, Lithofacies and biofacies of the Haney Limestone (Mississippian), Illinois, Indiana, and Kentucky: Kentucky Geol. Survey Thesis Ser. 4, 64 p.

Waddell, Courtney, 1954, Geology and coal deposits of the Shelburn Quadrangle, Sullivan County, Indiana: U.S. Geol. Survey Coal Inv. Map C–17, scale 1:24,000.

Wanless, H. R., 1955, Pennsylvanian rocks of Eastern Interior basin: Am. Assoc. Petroleum Geologists Bull., v. 39, no. 9, p. 1753–1820.

———1975, Illinois basin region, *in* McKee, E. D., and others Paleotectonic investigations of the Pennsylvanian System in the United States: U.S. Geological Survey Prof. Paper 853, pt. I, p. 71–95.

Wanless, H. R., and others, 1970, Late Paleozoic deltas in the central and eastern United States, *in* Morgan, J. P., ed., Deltaic sedimentation, modern and ancient: Soc. Econ. Paleontologists and Mineralogists Spec. Pub. 15, p. 215–245.

Wayne, W. J., 1970, Native Indiana iron ores and 19th century ironworks: Indiana Geol. Survey Bull. 42–E, 25 p.

Wayne, W. J., Johnson, G. H., and Keller, S. J., 1966, Geologic map of the 1°×2° Danville Quadrangle, Indiana and Illinois, showing bedrock and unconsolidated deposits: Indiana Geol. Survey Regional Geol. Map 2.

Whitfield, R. P., 1882, On the fauna of the Lower Carboniferous limestones of Spergen Hill, Indiana, . . .: Am. Mus. Nat. History Bull., v. 1, no. 3, p. 39–97.

Wier, C. E., 1950, Geology and coal deposits of the Jasonville quadrangle, Clay, Greene, and Sullivan Counties, Indiana: U.S. Geol. Survey Coal Inv. Map C–1, scale 1:24,000.

———1951, Geology and coal deposits of the Linton quadrangle, Greene and Sullivan Counties, Indiana: U.S. Geol. Survey Coal Inv. Map C–9, scale 1:24,000.

———1954, Geology and coal deposits of the Hymera Quadrangle, Sullivan County, Indiana: U.S. Geol. Survey Coal Inv. Map C–16, scale 1:24,000.

———1955, Correlation of the upper part of Pennsylvanian rocks in southwestern Indiana [unpub. Ph. D. thesis]: Bloomington, Indiana Univ., 109 p.

———1960, Stratigraphic relations of the Merom Sandstone near Merom, Indiana, Indiana Acad. Sci. Proc., v. 69, p. 217–223.

———1973, Coal resources of Indiana: Indiana Geol. Survey Bull. 42–I, 40 p.

Wier, C. E., and Girdley, W. A., 1963, Distribution of the Inglefield and Dicksburg Hills Sandstone Members in Posey and Vanderburgh Counties, Indiana: Indiana Acad. Sci. Proc. 1962, v. 72, p. 212–217.

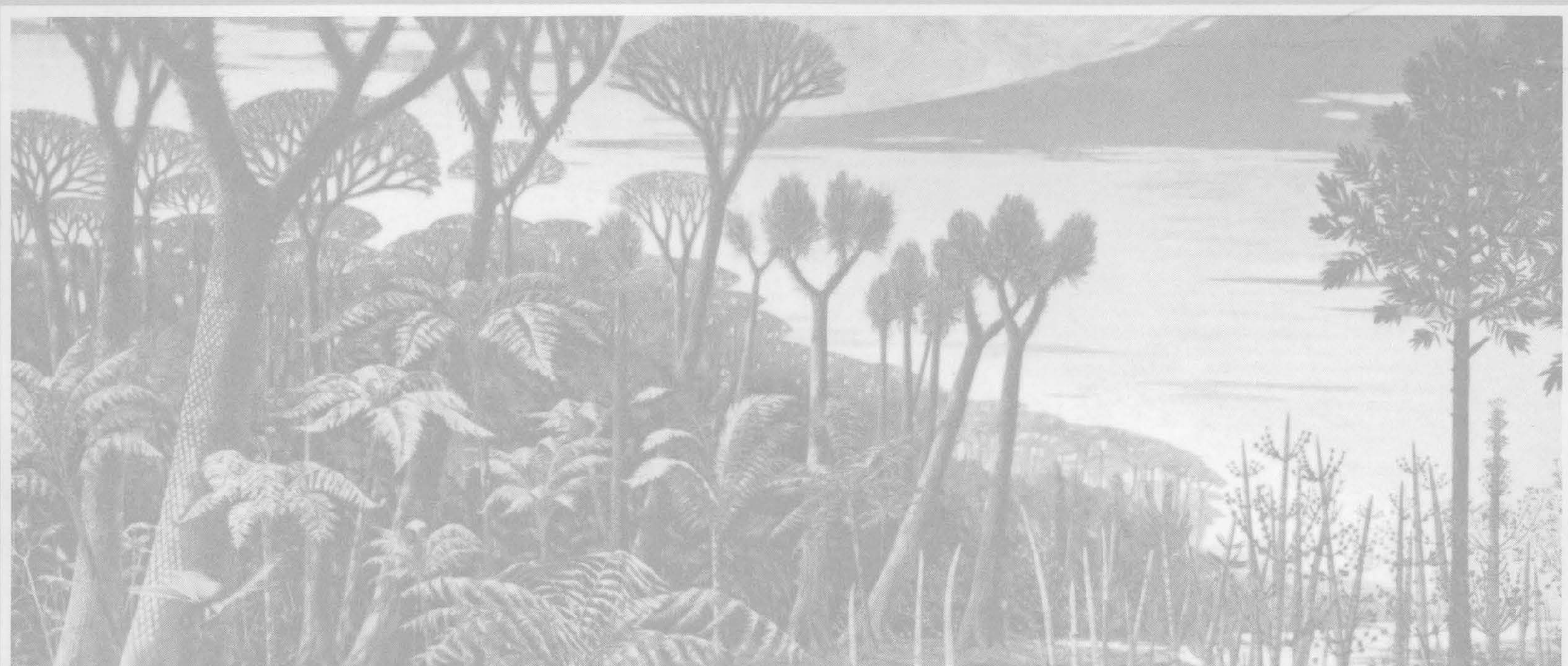
Wier, C. E., and Gray, H. H., 1961, Geologic map of the Indianapolis 1°×2° quadrangle, Indiana and Illinois showing bedrock and unconsolidated deposits: Indiana Geol. Survey Regional Geol. Map [1], scale 1:250,000.

Willman, H. B., and others, 1975, Handbook of Illinois stratigraphy: Illinois State Geol. Survey Bull. 95, 261 p.

Wood, J. M., 1963, The Stanley Cemetery flora (early Pennsylvanian) of Greene County, Indiana: Indiana Geol. Survey Bull. 29, 73 p.

Zangerl, Rainer, and Richardson, E. S., Jr., 1963, The paleoecological history of two Pennsylvanian black shales: Fieldiana—Geology Mem., v. 4, 352 p.

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



GEOLOGICAL SURVEY PROFESSIONAL PAPER 1110–A–L

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.)

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

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

E. Ohio, by Horace R. Collins

F. Kentucky, by Charles L. Rice, Edward G. Sable, Garland R. Dever, Jr., and Thomas M. Kehn

G. Tennessee, by Robert C. Milici, Garrett Briggs, Larry M. Knox, Preston D. Sitterly, and Anthony T. Statler

H. Georgia, by William A. Thomas and Howard R. Cramer

I. Alabama and Mississippi
   Mississippian stratigraphy of Alabama, by William A. Thomas
   Pennsylvanian stratigraphy of Alabama, by Everett Smith
   Carboniferous outcrops of Mississippi, by Alvin R. Bicker, Jr.

J. Michigan, by Garland D. Ells

K. Indiana, by Henry H. Gray

L. Illinois, by Elwood Atherton and James E. Palmer

GEOLOGICAL SURVEY PROFESSIONAL PAPER 1110-A-L

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1979

UNITED STATES DEPARTMENT OF THE INTERIOR

CECIL D. ANDRUS, ***Secretary***

GEOLOGICAL SURVEY

H. William Menard, ***Director***

Library of Congress catalog-card No. 79-52491

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402

Stock Number 024-001-03174-4

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.

FOREWORD

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

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

CONTENTS