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

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Historical review and summary of areal, stratigraphic, structural, and economic geology of Mississippian and Pennsylvanian rocks in Pennsylvania and southwestern New York

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ABSTRACT

The Mississippian and Pennsylvanian rocks of Pennsylvania and New York constitute a dominantly clastic sequence 700 to 3,200 m (2,300 to 10,500 ft) thick. Deposited during the late stages of formation of the Appalachian geosyncline, most Mississippian and Pennsylvanian sediments issued from the Acadian orogenic highlands to the southeast along the presumed impact zone of the North American and African continental plates. Less sediment came from the rim of the North American craton to the north and the older Taconic orogenic highlands to the northeast. Paleomagnetic studies suggest that the Pennsylvania-New York area was slightly south of the equator during Mississippian and Pennsylvanian time; examination of the fossil flora indicates a mostly subtropical climate.

Of the seven alternating clastic and carbonate sequences that make up the Appalachian Paleozoic, the Mississippian-Pennsylvanian includes parts of the last two clastic sequences and a thin representative of the last intervening carbonate sequence. These three primary Paleozoic units may be divided into eight major lithologic groupings, which are described herein under 15 principal formations or groups. Two widespread disconformities exist from upper middle Mississippian through lower Middle Pennsylvanian across New York and northern Pennsylvania and possibly beyond.

Biostratigraphic zonation of the Carboniferous of Pennsylvania and New York has not been accomplished yet. The marine Mississippian strata of northwestern Pennsylvania have an abundant fossil invertebrate suite, but most research has been directed toward locating the Devonian-Mississippian boundary. Various avenues of paleozoological research are yet to be followed in both the Mississippian and Pennsylvanian, in order to establish true biozones and correlations with the midcontinent.

The Mississippian has been divided into three and the Pennsylvanian into nine presumably time-sequential botanical biostratigraphic zones.

The Devonian-Mississippian boundary within the marine section of northwestern Pennsylvania is fairly well located; the Mississippian-Pennsylvanian boundary is accurately located where disconformable. Elsewhere, these two boundaries are only approximate. The Pennsylvanian-Permian boundary is controversial. Epoch boundaries, except the Desmoinesian and, locally, the Missourian, are indistinct.

The depositional history of the Mississippian-Pennsylvanian consisted of the following events in chronological order: (1) Late Devonian and Early Mississippian marine transgression; (2) Early Mississippian stable, delta-dominated coast; (3) early middle Mississippian formation of elongate braided alluvial-deltaic sand plain; (4) late middle Mississippian initiation of Mauch Chunk delta in southeast Pennsylvania and epeirogenic uplift of northern Pennsylvania and New York; a shallow marine invasion from the southwest was interposed between the delta and upwarped area; (5) Late Mississippian and Early Pennsylvanian prograding of Mauch Chunk delta and continued erosion in northern Pennsylvania and New York; (6) Early Pennsylvanian alluvial plain established across all of Pennsylvania; (7) Middle Pennsylvanian marine influence in western Pennsylvania established shallow-marine—delta-plain—alluvial-plain conditions from west to east; (8) Middle Pennsylvanian westward prograding of depositional environment, limiting Pennsylvania to nonmarine deltaic and alluvial conditions; (9) middle Late Pennsylvanian marine incursions into Pennsylvania; (10) reduction of depositional environment to shallow estuary remote from marine conditions during Late Pennsylvanian; (11) Late Pennsylvanian-Permian coastal-plain lacustrine environment, apparently severed from marine connection.

In Pennsylvania, recoverable coal resources more than 61 cm thick amount to approximately 30 billion metric tons. Coal heat value ranges from 8,200 to 8,800 calories per gram (14,700 to 15,800 Btu per pound) on a dry, ash-free basis. Pennsylvania coal production in 1976 was 85.6 million metric tons.

Oil and gas production from Mississippian and Pennsylvanian rocks is small. Raw materials for a wide variety of ceramic products are available from Pennsylvanian and some Mississippian units.

INTRODUCTION

The Carboniferous of Pennsylvania and New York is an overwhelmingly clastic sequence containing subordinate amounts of limestone and coal. Strata of Mississippian and Pennsylvanian age underlie approximately 45 percent of Pennsylvania but extend into New York only as small outliers aggregating a few square kilometers (fig. 1). Where

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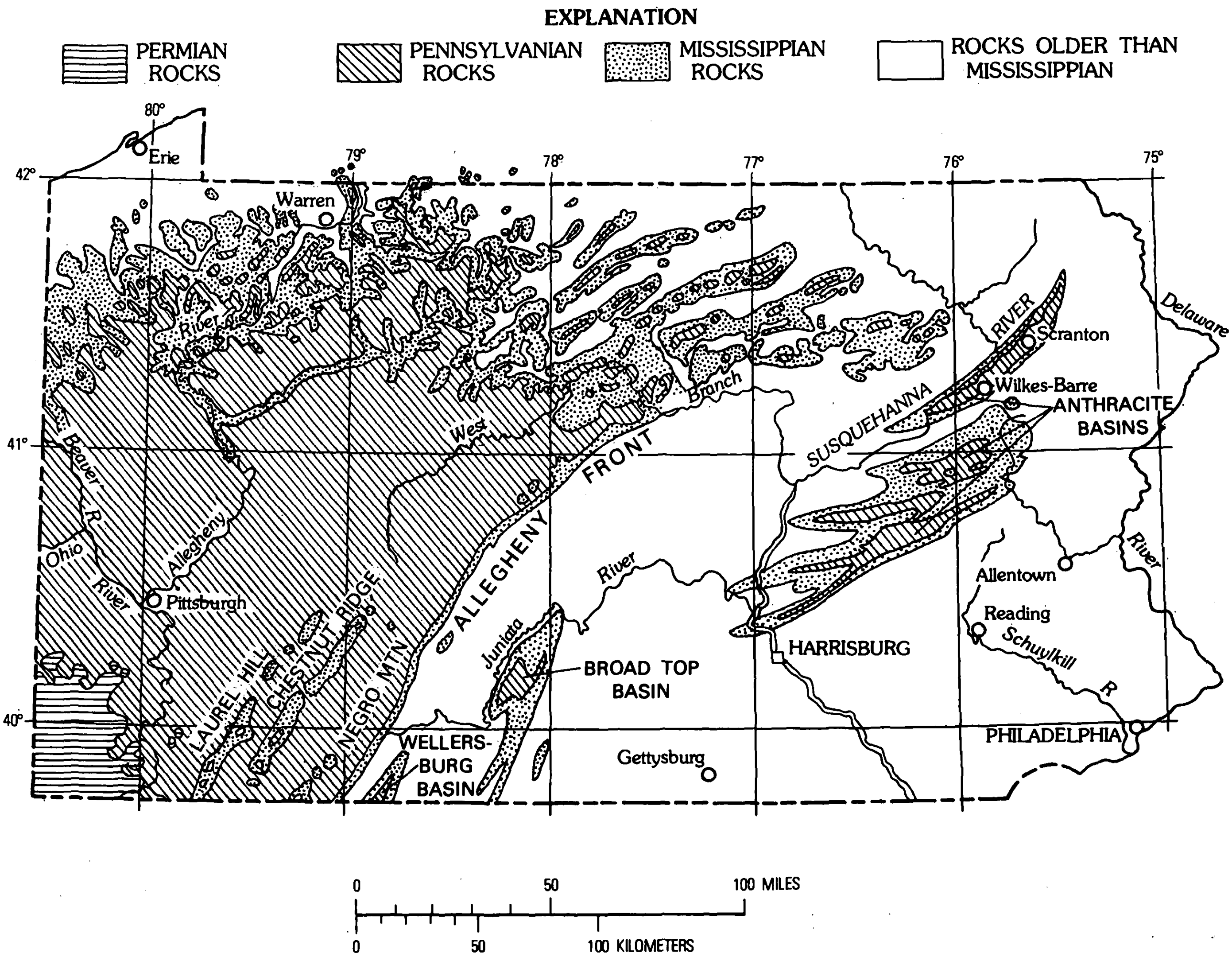

FIGURE 1.—Outcrop of Mississippian and Pennsylvanian rocks in Pennsylvania and New York.

uninterrupted by unconformities, the Mississippian and Pennsylvanian together constitute about 25 percent of the total Paleozoic.

The demonstrable thickness of combined Mississippian and Pennsylvanian rocks ranges from about 700 m (2,300 ft) in southwestern Pennsylvania to 3,000–3,200 m (10,000–10,500 ft) at the Schuylkill River Gap in the Southern Anthracite field. Both a smaller minimum and larger maximum can be inferred in other areas but cannot be demonstrated directly, as the section is incomplete. As an example, in the area around Olean, N.Y., basal Pennsylvanian rocks rest disconformably upon the uppermost Devonian; a reconstructed Pennsylvanian probably would not exceed 450 m (1,500 ft).

The Mississippian and Pennsylvanian sequence contains two widespread resistant sandstone intervals which are prominent ridge and scarp formers across much of Pennsylvania. The lower of these two intervals is the Mississippian Pocono-Burgoon sandstone and conglomerate; the higher is the sandstone and conglomerate of the Pennsylvanian Pottsville Formation. Individually or jointly, the Burgoon-Pocono and the Pottsville sustain the high ridges surrounding the four anthacite basins and the Broad Top and Wellersburg basins. They also form the lip of the Allegheny Front escarpment and the cores of Laurel Hill, Chestnut Ridge, and Negro Mountain.

Mississippian and Lower Pennsylvanian rocks are best exposed along the Allegheny Front; around the Wellersburg, Broad Top, and the four anthracite basins; along the West Branch of the Susquehanna

River and the upper reaches of the Allegheny River and their tributaries; and on the flanks of Laurel Hill and Chestnut Ridge. The Middle and Upper Pennsylvanian sequence is fairly well exposed along the Monongahela, Allegheny, and Ohio Rivers and their major tributaries; the headwaters of the West Branch of the Susquehanna River; and in many major excavations in the Pittsburgh metropolitan area. Many good exposures of various parts of the section are found along the major Interstate Highways such as I-70, I-76 (Pennsylvania Turnpike), I-79, I-80, and I-81. Excellent exposures of the Mississippian occur in the Lehigh River gorge near Jim Thorpe, and excellent exposures of both Mississippian and Pennsylvanian strata are to be found in the vicinity of Pottsville.

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 Pennsylvania Geological Survey and the New York State Museum—Geological Survey.

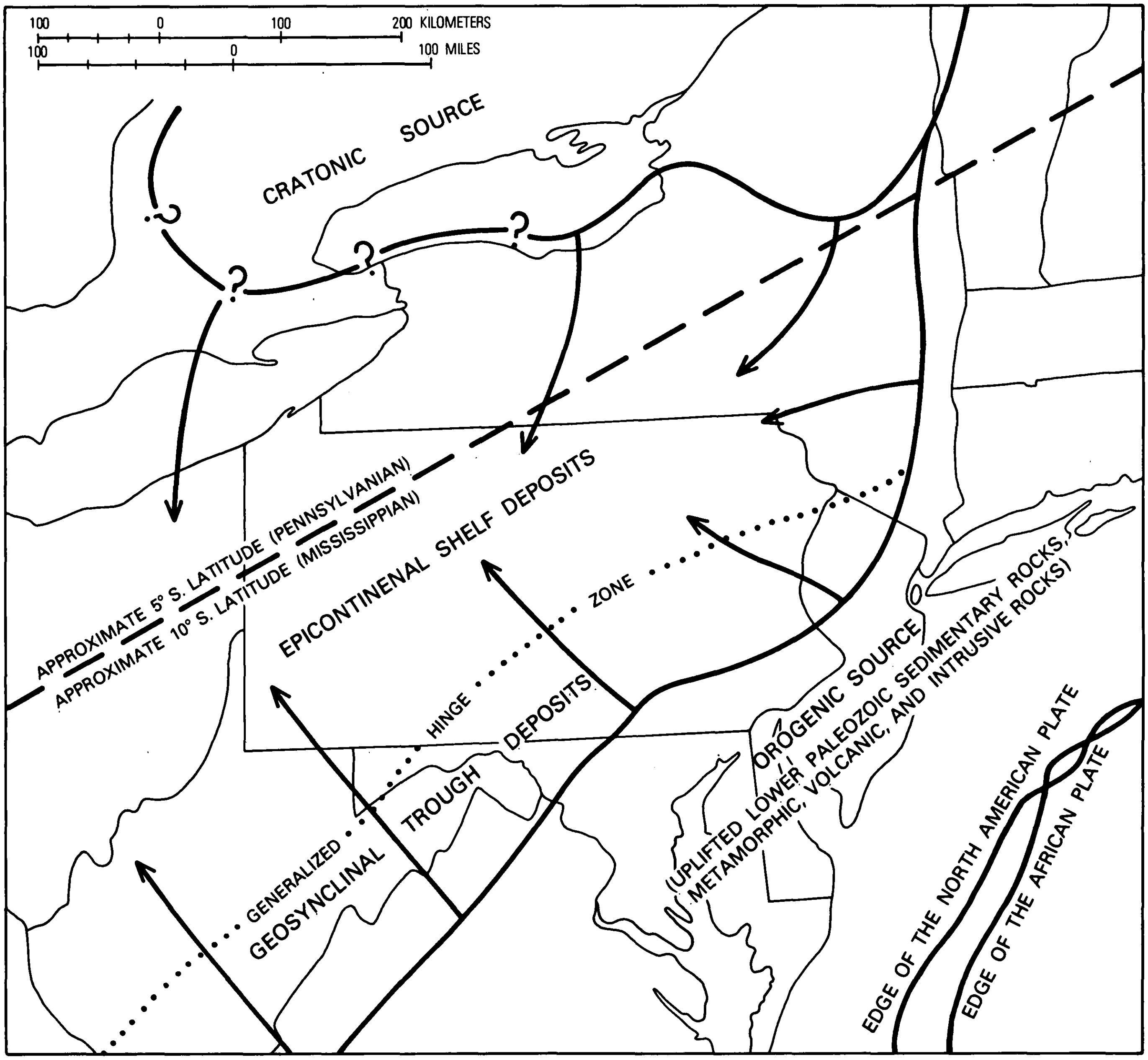

FIGURE 2.—Generalized paleogeography of the Mississippian-Pennsylvanian depositional basin and source areas.

GENERAL GEOLOGIC SETTING

THE APPALACHIAN GEOSYNCLINE

Mississippian and Pennsylvanian rocks were deposited during the late stages of formation of the Appalachian geosyncline. Dietz (1972) postulated that the Appalachian geosyncline formed along the eastern edge of the North American continental plate when this plate initially separated from the northwest African plate during the late Precambrian, thus opening the proto-Atlantic epicontinental seaway.

During the Ordovician Period, the North American and African plates began to close again, crumpling the outer edge of the Appalachian geosyncline. By Mississippian time, the two plates were virtually in contact (Hurley, 1968; Schopf, 1975, p. 26), and large volumes of sediment were being carried westward from the orogenic mountains upthrust along the continental margin toward the cratonic core of North America (fig. 2).
These sediments along with a smaller volume issuing from the craton formed the Appalachian exogeosyncline of Kay (1951, p. 17 and pl. 5) and the continental-shelf deposits.

From Silurian time onward, the geosyncline apparently was sealed off at the northern end in eastern New York where the Taconic orogenic mountains were driven against the Adirondack cratonic high. The eastern orogenic source extended southwestward from the Taconic uplift area through the present location of Philadelphia and Baltimore and beyond.

Mountain building associated with the impact of the two continental plates was intermittent. After the Late Ordovician Taconic culmination, the Acadian orogeny, during Middle to Late Devonian time, produced the sediments of the Upper Devonian Catskill delta. Effects of Acadian mountain building continued, but with diminishing intensity, into the middle Mississippian.

A third orogeny produced the Mauch Chunk delta during middle to Late Mississippian and culminated in the Early Pennsylvanian, when the Pottsville sandstone and conglomerate spread westward. Approximately contemporaneously with this continental-margin orogeny, epeirogenic upwarping along the craton margin uplifted central and western New York and northern Pennsylvania to the point at which further deposition ceased and some erosion of Lower Mississippian units took place.

Continued collision of the continental margins in the late part of the Permian Period—the Appalachian Revolution—produced the massive folding that terminated formation of the classic Appalachian geosyncline. Triassic sediments were deposited in the narrow fault-block basins formed during separation of the North American and African plates.

It should be noted that many workers believe that Appalachian geosynclinal development and deformation resulted from causes other than the movement of continental plates described above.

CLIMATE

Paleomagnetic studies of rocks of Mississippian and Pennsylvanian age (Turner and Tarling, 1975), suggest that Pennsylvania and New York lay slightly south of the equator at that time (fig. 2). Examination of the Mississippian-Pennsylvanian flora by White (1913) and by Köppen and Wegener (1924) indicated a subtropical setting, although probably not as intensely hot as a low-elevation equatorial setting today would imply. Camp (1956) concluded that Pennsylvania and New York lay near the equator in an area that generally received abundant year-round rainfall.

White (1913, p. 74) considered the Mississippian flora to be rather impoverished and stunted, a fact suggesting that climatic conditions were less than ideal. He further noted that the striking evolution of new plant forms in the Early Pennsylvanian suggests optimum temperature and rainfall conditions. White believed that Middle Pennsylvanian vegetation was somewhat less lush and that a drier period prevailed during late Middle and early Late Pennsylvanian. Latest Pennsylvanian floras reflect a return to a substantially better climate.

LITHOSTRATIGRAPHY

GENERAL

The most basic or first-order subdivisions of the Paleozoic sedimentary rocks of the Appalachian geosyncline are the seven alternating clastic and carbonate sequences shown in figure 3. The Mississippian and Pennsylvanian of Pennsylvania span part of the upper two clastic divisions (Devonian-Mississippian and Mississippian-Permian) and include a thin representative of the intervening Mississippian carbonate rocks. These first-order stratigraphic units can be further divided into major second-order lithologic groupings as shown in figure 4.

The Devonian-Mississippian second-order units of figure 4 are derived conceptually from the "magnafacies" of Caster (1934). The "marine black shale" is, in essence, Caster's Cleveland Magnafacies. The

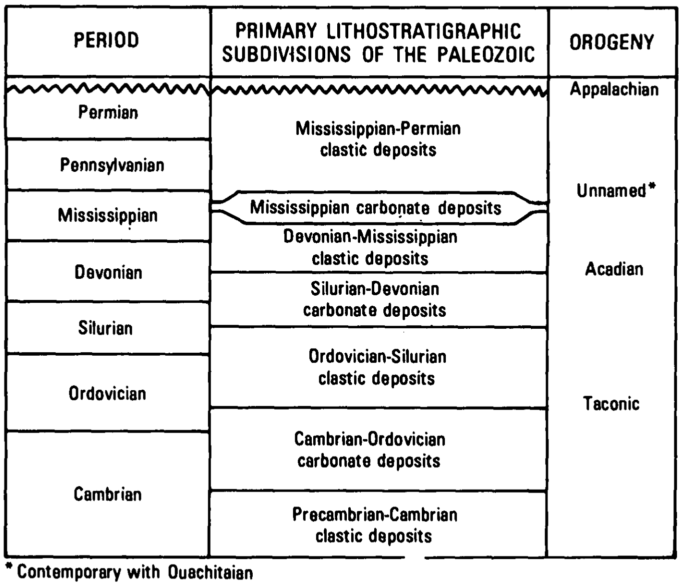

FIGURE 3.—Primary lithostratigraphic subdivisions of the Paleozoic.

"marine fine-grained clastic rocks" and "marine mixed clastic rocks" of figure 4 are equivalent to Caster's Chagrin and Big Bend Magnafacies. The "red, nonmarine mixed clastic rocks" are Caster's Catskill Magnafacies. The "nonred, nonmarine mixed clastic rocks" of figure 4 are equivalent, to the best of our understanding, to Caster's Tioga Magnafacies. The "light gray, nonmarine sandstone and conglomerate" is in essence, Caster's Pocono Magnafacies.

The present lithostratigraphic nomenclature has evolved slowly through the efforts of scores of workers during the past 140 years. The formal terminology used in this report (fig. 5) is that used in the 1979 edition of the Geologic Map of Pennsylvania (Berg and others, 1979). The roots of most groups and formations shown in figure 5 (if not their precise definition and name) were established during the 19th and early 20th centuries. Only the Huntley Mountain, Spechty Kopf, Casselman, and Glenshaw Formations are conceptually of recent origin.

All units are strictly lithostratigraphic and are not intended to have any inherent biostratigraphic or chronostratigraphic connotation. The relationship between the formal stratigraphic terms given in figure 5 and the first- and second-order Paleozoic subdivisions given in figures 3 and 4 are summarized in figure 6.

All Mississippian units are defined by their bulk lithologic character and are distinguished from contiguous units by fairly distinct lithologic differences. Most units reflect more or less discrete depositional environments. As can be seen in figure 6, there is a high degree of conformity and little overlap between Mississippian nomenclature and the second-order lithologic subdivisions of the upper Paleozoic of Pennsylvania.

In contrast, most Pennsylvanian units are not defined by any bulk lithologic homogeneity but are instead intervals bounded by key beds that are as-

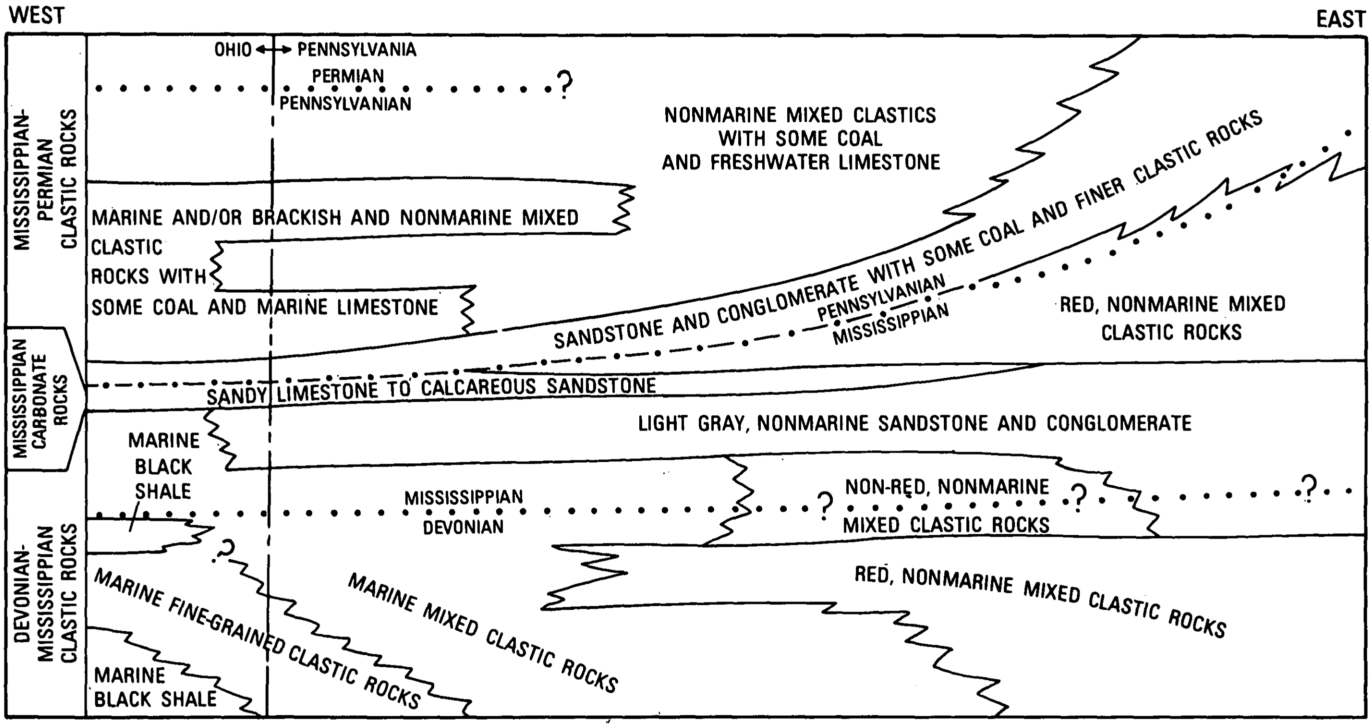

FIGURE 4.—Diagrammatic cross section showing the relation of second-order to first-order middle and late Paleozoic lithologic subdivisions.

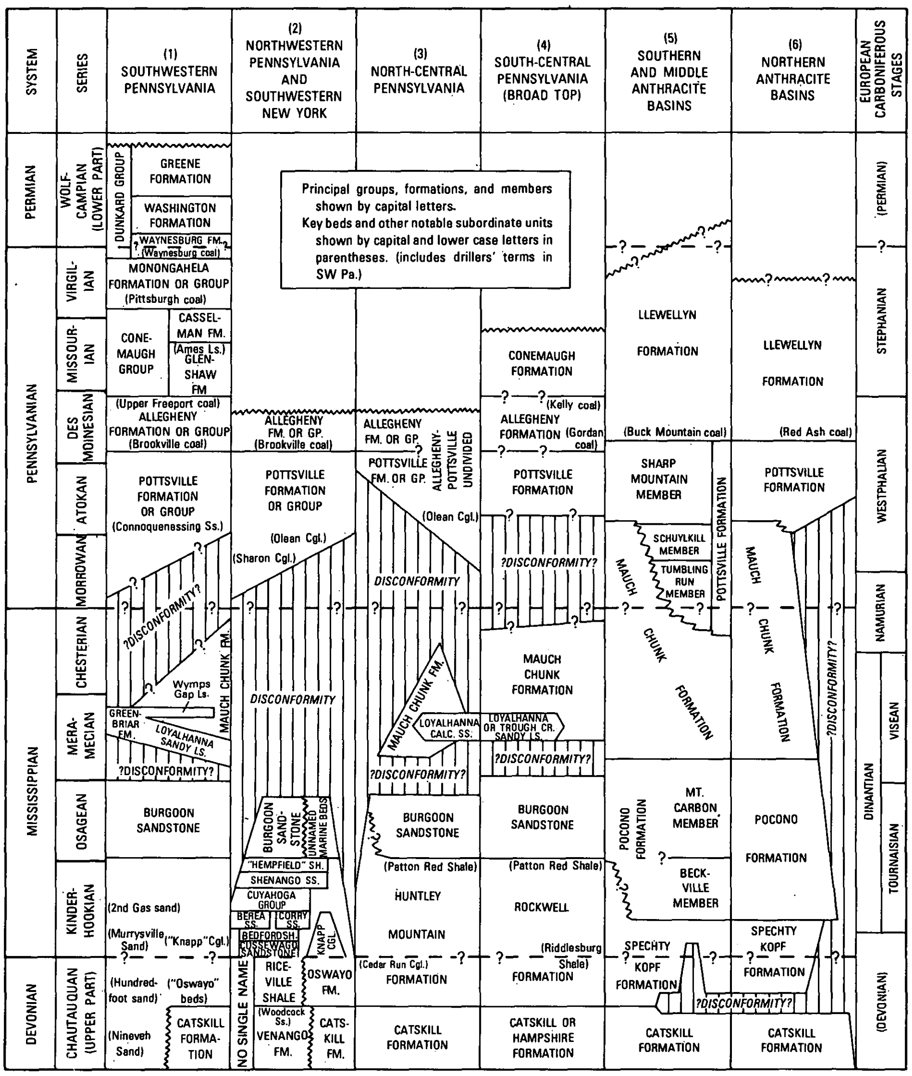

FIGURE 5.—Correlation chart of Mississippian and Pennsylvanian rocks in Pennsylvania and New York.

sumed (sometimes fallaciously) to be both distinctive and widely continuous. Aside from the lower Pottsville sandstone and conglomerate, there is no dominant lithologic distinctiveness to any substantial part of the Pennsylvanian. All is a more or less heterogeneous mixture of sandstone, shale, claystone, limestone, and coal. Such differences as do exist are subtle variations in proportion, such as a change from 4 or 5 percent coal within the Allegheny Group to 1 or 2 percent in the Conemaugh Group. For this reason, there is a large amount of overlap between the nomenclature and the second-order divisions in figure 6.

Most of the unit-defining key beds are coal, and, with one exception, all generally fail to meet the strict requirements of widespread continuity and distinctiveness expected of a key bed. Boundaries of most Pennsylvanian units are projected on interval, on sequence among a multiplicity of overlapping local beds and lenses, and on the above-mentioned subtle variations in lithologic proportion. Pennsylvanian lithostratigraphic subdivision will not easily stand rigorous application of the standard rules of stratigraphic nomenclature.

Stratigraphic relationships among the Mississippian and Pennsylvanian units given in figure 5 across Pennsylvania are shown in the panel diagrams of figures 7 through 10.

RICEVILLE-OSWAYO THROUGH "HEMPFIELD" SEQUENCE

(Figure 5, column 2)

The Riceville-Oswayo through "Hempfield" sequence in northwestern Pennsylvania spans the Devonian-Mississippian boundary and is a mixture of fine-grained sandstone, siltstone, and shale, contain-

FIRST-ORDER LITHOLOGIC DIVISIONS OF THE APPALACHIAN PALEOZOIC (FIGURE 3)	SECOND-ORDER LITHOLOGIC DIVISIONS OF THE APPALACHIAN PALEOZOIC IN PENNSYLVANIA (FIGURE 4)	LITHOSTRATIGRAPHIC NOMENCLATURE (FIGURE 5)
Mississippian-Permian clastic rocks (lower part)	Nonmarine mixed clastic deposits with some coal and fresh-water limestone.	Dunkard Group (Permian) Monongahela Group or Formation Casselman Formation Conemaugh Group (S. central Pa.) Upper Allegheny Group (SW. and NW. Pa.) Allegheny Group (N. central and S. central Pa.) Upper Pottsville Group (N. central and S. central Pa.)
	Marine and/or brackish and nonmarine mixed clastic deposits with some coal and marine limestone	Glenshaw Formation (SW. Pa.) Lower Allegheny Group (SW. and NW. Pa.) Upper Pottsville Formation or Group (SW. and NW. Pa.)
	Sandstone and conglomerate with some coal and finer clastic deposits	Llewellyn Formation Lower Pottsville Formation or Group (western and central Pa. and SW. N.Y.) Pottsville Formation (eastern Pa.)
Mississippian carbonate rocks	Limestone to calcareous sandstone	Greenbriar Formation Loyalhanna Formation Wymps Gap Member of Mauch Chunk Formation
Devonian-Mississippian clastic rocks (upper part)	Red, nonmarine mixed clastic deposits (Mississippian)	Mauch Chunk Formation
	Light gray, nonmarine sandstone and conglomerate	Burgoon Sandstone Pocono Formation Spechty Kopf Formation (in part)
	Non-red, nonmarine mixed clastic deposits	Rockwell Formation Huntley Mountain Formation Spechty Kopf Formation (in part)
	Marine mixed clastic deposits	Unnamed marine equivalents of Burgoon Sandstone Riceville-Oswayo through "Hempfield" sequence Venango Formation (Devonian)
	Red nonmarine mixed clastic deposits (Devonian)	Catskill (Hampshire) Formation (Devonian)
	Marine fine grained clastic deposits	Not represented in figure 5
	Marine black shale	Not represented in figure 5

FIGURE 6.—The relation of first-order and second-order Paleozoic lithologic subdivisions to stratigraphic nomenclature.

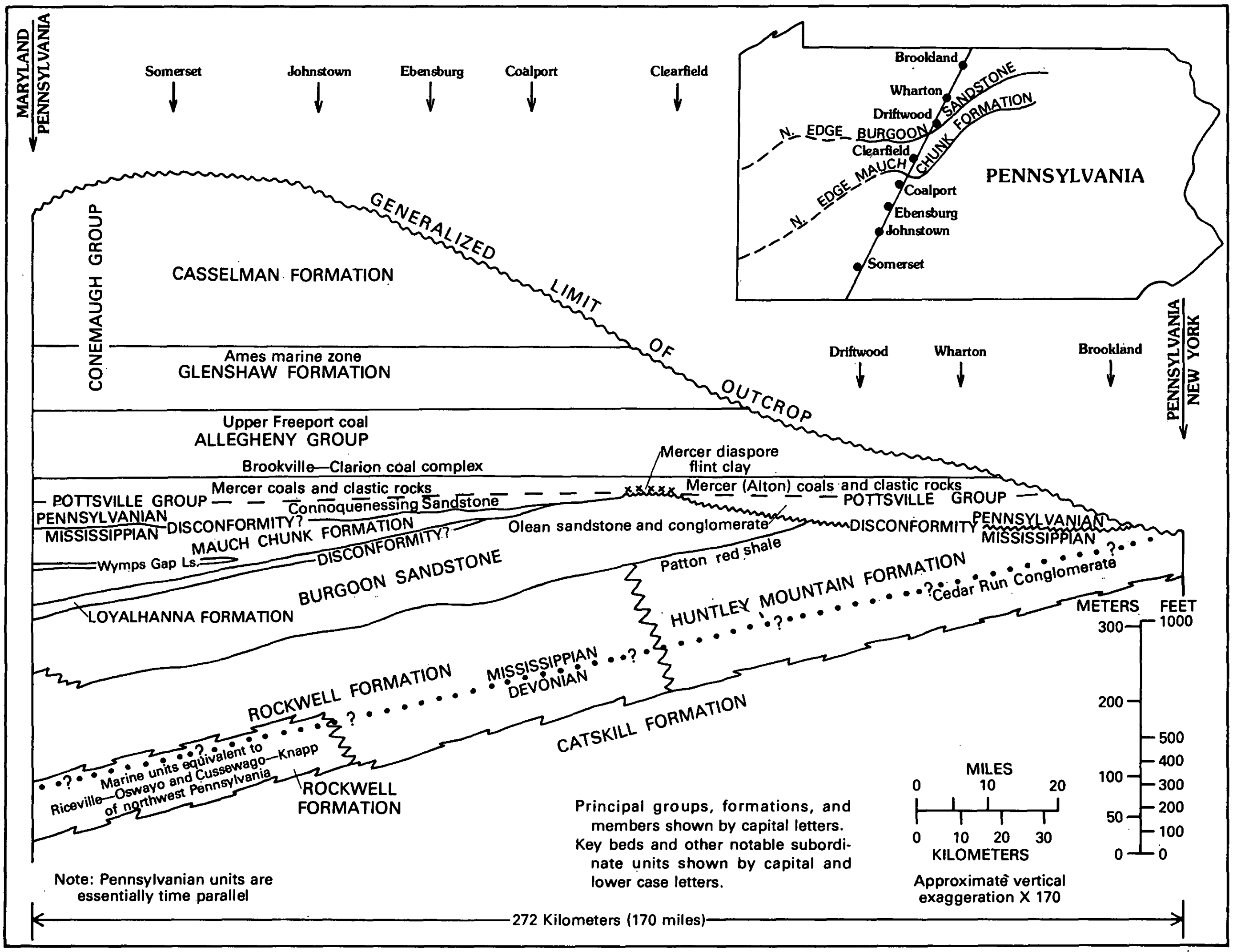

FIGURE 7.—Generalized stratigraphic cross section of Mississippian and Pennsylvanian rocks from Somerset County, Pa., to Cattaraugus County, N.Y.

ing occasional zones of flat-pebble conglomerate. Sandstones and intervening finer grained units have been named individually, but the entire sequence has no collective name. As long as individual units persist, this system of individual names works well. When, however, a component (usually one of the sandstones) disappears laterally, the nomenclature breaks down, resulting in the nameless gaps appearing in figure 5, column 2 bottom. The name "Hempfield" for the shale sequence overlying the Shenango Sandstone proposed by Caster (1934) is flawed by an erroneous type section, based on a miscorrelation in which the shale cited actually underlies the Shenango Sandstone rather than overlying it as Caster intended (Kimmel and Schiner, 1970). Kimmel and Schiner (1970) chose to correct the error by incorporating the shale overlying the Shenango Sandstone into an extended Shenango Formation as an unnamed upper member. It would be preferable to retain the name "Shenango" for the sandstone alone and to formally name the shale above the Shenango Sandstone. The informal term "Hempfield" is used in this report when the unit in question is discussed.

Shale and siltstone in this sequence are generally dark gray to medium dark gray, weathering to light olive gray or olive gray. Some shale is also grayish red to grayish brown. Sandstone is medium light gray to olive gray and has planar bedding and small- to medium-scale crossbedding. These rocks frequently have an abundant and diverse marine invertebrate fauna, extensive bioturbation, numerous trace fossils, some fish remains, and rare plant frag-

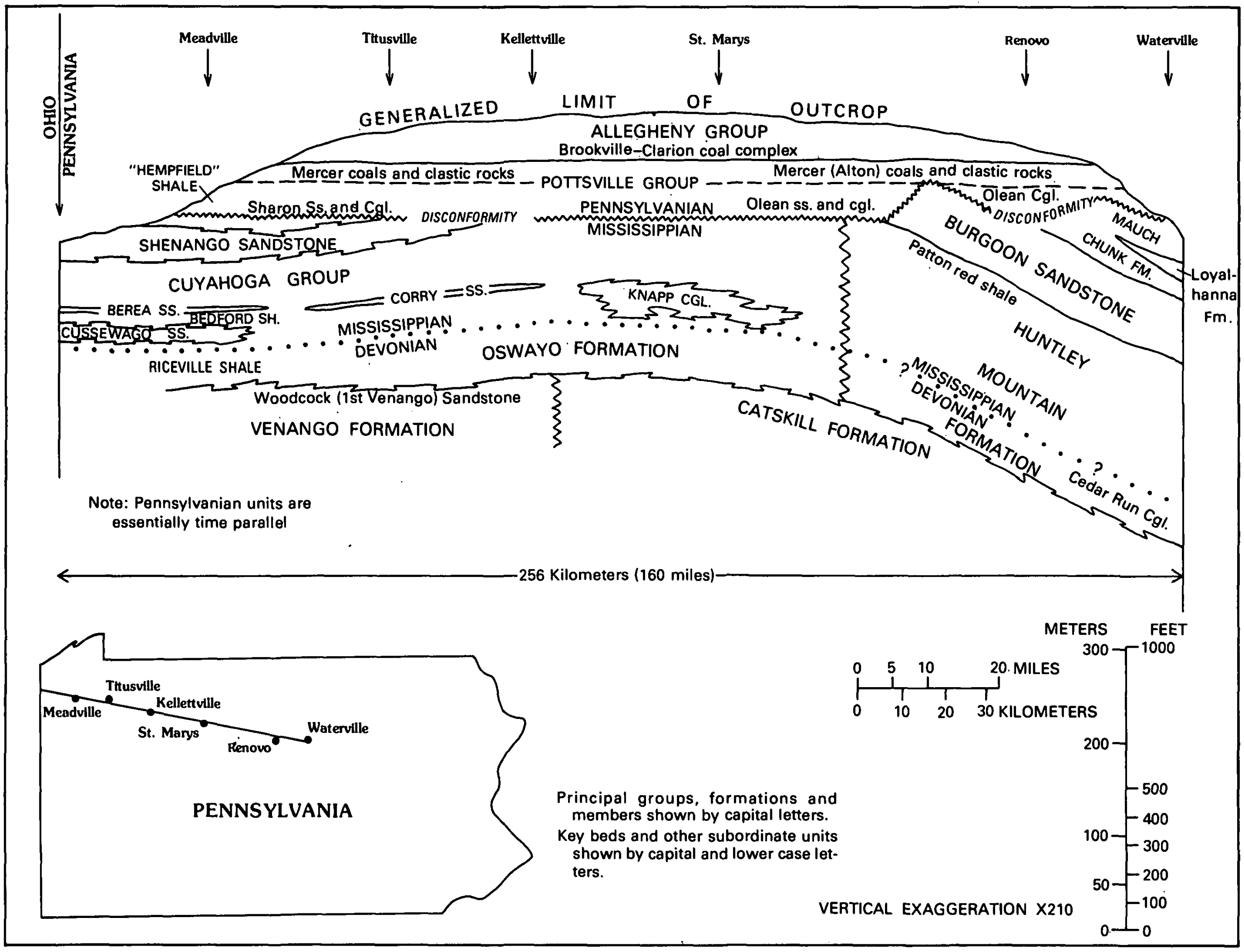

FIGURE 8.—Generalized stratigraphic cross section of Mississippian and Pennsylvanian rocks from Lycoming County, through Crawford County, Pa.

ments. Where completely present, the Riceville-Oswayo through "Hempfield" is about 180 to 215 m (600 to 700 ft) thick.

The "unnamed marine clastics" which are laterally equivalent to the Burgoon Sandstone (fig. 5, column 2) are also, logically, an upward continuation of Riceville-Oswayo through "Hempfield" sequence. Only recently recognized, these post-"Hempfield" marine rocks are exposed at the surface in limited areas in northern Armstrong and northwest Indiana Counties. They probably continue in the subsurface westward to Ohio, where a similar relationship is noted between the Logan (Burgoon) Sandstone and laterally equivalent marine beds.

The transgressive marine Riceville-Oswayo through "Hempfield" sequence that overlies the regressive marine Venango Formation and prograding nonmarine Catskill Formation is the facies equivalent of the dominantly nonmarine Huntley Mountain and Rockwell Formations. The sub-Burgoon section in the subsurface of southwestern Pennsylvania (fig. 5, column 1) is essentially a continuation of the general Riceville-Oswayo through "Hempfield" marine interval.

This sequence, along with the unnamed marine equivalents of the Burgoon, is approximately correlative with the Waverly Group of Ohio.

ROCKWELL, HUNTLEY MOUNTAIN, AND SPECHTY KOPF FORMATIONS
(Figure 5, columns 3–6)

The Rockwell Formation, Huntley Mountain Formation (Berg and Edmunds, 1979), and, in most areas, the Spechty Kopf Formation are a dominantly

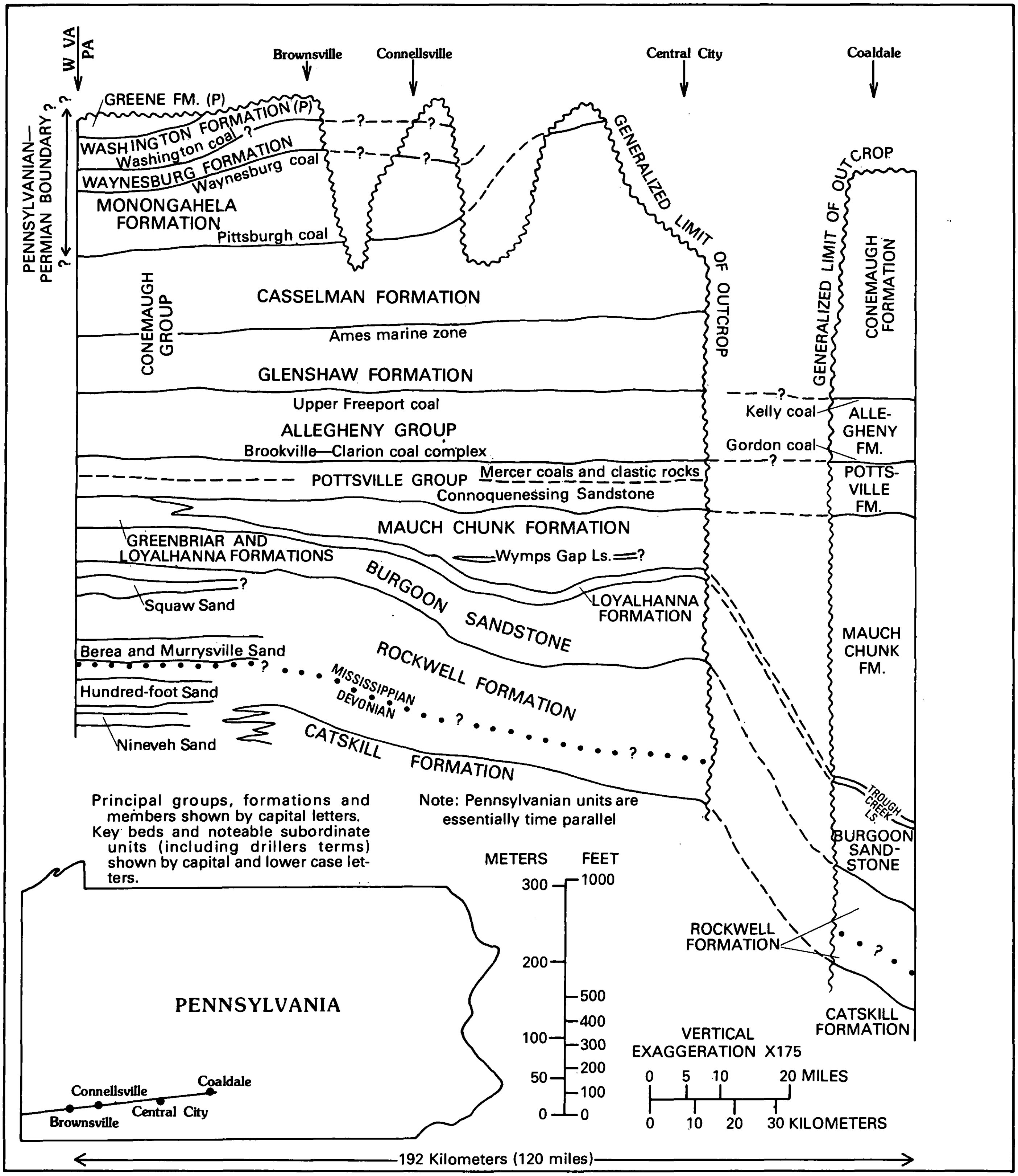

FIGURE 9.—Generalized stratigraphic cross section of Mississippian and Pennsylvanian rocks from Bedford County, through Washington County, Pa.

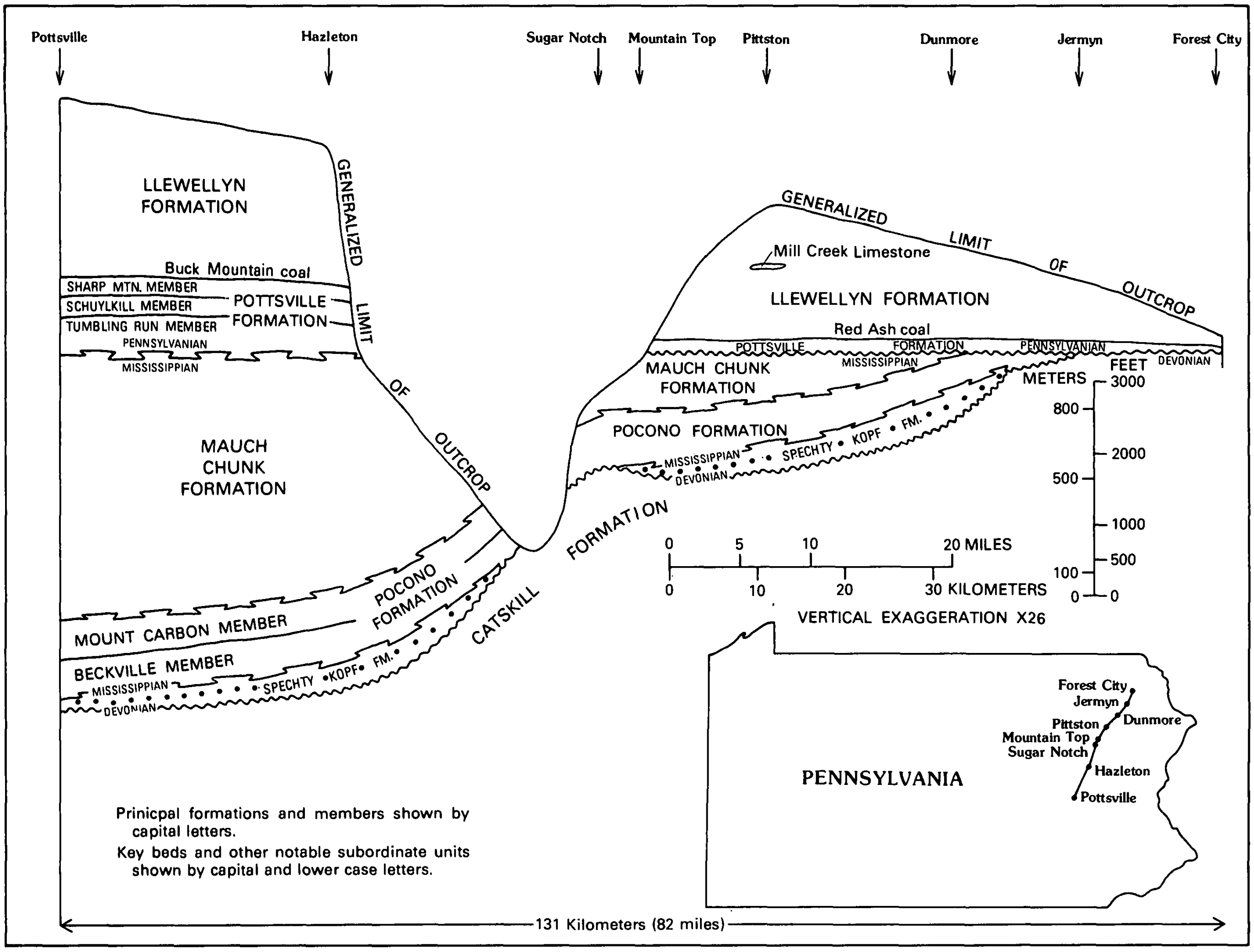

FIGURE 10.—Generalized stratigraphic cross section of Mississippian and Pennsylvanian rocks from Schuylkill County to Susquehanna County, Pa.

nonmarine mixture of sandstone, siltstone, and shale.

All three units are lateral equivalents of one another and of the lower part of the Pocono Sandstone of northeastern Pennsylvania as well. In its type area around the western end of the Southern Anthracite field, the Spechty Kopf is almost entirely sandstone and lithologically is a continuation of the overlying Pocono. Elsewhere, the Spechty Kopf is the nonmarine mixture mentioned above and is generally rather similar to the Rockwell Formation, except for the lack of red beds.

The Rockwell and Huntley Mountain are dominantly nonmarine facies equivalents of the Riceville-Oswayo through "Hempfield" marine sequence of northwestern Pennsylvania; they interfinger with marine beds along their western margin. A few marine units, such as the Cedar Run conglomerate bed of the Huntley Mountain and the Riddlesburg shale member of the Rockwell represent strong, but brief, eastward marine transgressions.

There is some indication that the Huntley Mountain thickens in north-central Pennsylvania, replacing the Burgoon Sandstone by facies change in much the same way that the Burgoon is replaced by marine facies equivalents in northwestern Pennsylvania. In western Maryland, the Rockwell seems to replace the Burgoon in a similar way.

The sandstone, siltstone, and shale of these formations are generally various shades of gray or greenish gray. Plant fossils are sometimes present. The Rockwell and Huntley Mountain contain scattered grayish-red shale and some thin beds or lenses of flat pebble conglomerate. The Spechty Kopf and Rockwell locally contain notable occurrences of diamictite, which may be glacial or glaciofluvial deposits (Sevon 1973).

The Huntley Mountain is distinguished from the Rockwell and Spechty Kopf by its overall greenish or olive cast and by much thin flaggy sandstone. The Huntley Mountain has more lithic affinity to the underlying Catskill Formation, whereas the Spechty Kopf and Rockwell appear to have more lithic affinity to the overlying Pocono Formation. The distinctiveness of the Huntley Mountain Formation is believed to stem from differences in provenance and basin characteristics. The sediment source for the Spechty Kopf and Rockwell was the "new" orogenic belt to the southeast (Pelletier, 1958), whereas the Huntley Mountain may have been derived partly from the old Taconic Highlands to the northeast and possibly the craton to the north as well. In addition, the Huntley Mountain was deposited in the more restricted northeastern end of the Appalachian basin.

The Rockwell, Huntley Mountain, and Spechty Kopf Formations are generally 180 to 250 m (600 to 800 ft) thick. Where they apparently replace the Burgoon Sandstone laterally, the Huntley Mountain and Rockwell may expand to 300 m (1,000 ft).

POCONO, BURGOON, AND SPECHTY KOPF FORMATIONS
(Figure 5, all columns)

The Pocono and Burgoon Formations and, in its type area around the western end of the Southern Anthracite field, the Spechty Kopf Formation are dominantly medium- to coarse-grained, medium-light to very light gray sandstone often containing quartz pebble conglomerate zones. No red beds are present, but subordinate dark shale and siltstone are found. The Pocono is as much as 500 m (1,650 ft) thick and the Burgoon as much as 110 m (360 ft). Plant fossils are common, especially in the finer grained lenses, but no marine invertebrate fossils are found.

The Burgoon appears to be the westward extension of the upper part of the Pocono. Around its depositional margins, the Pocono-Burgoon appears to grade laterally into upward extensions of subjacent units: the Huntley Mountain Formation in north-central Pennsylvania; the lower Mississippian marine clastic rocks of northwestern Pennsylvania and Ohio; and the Rockwell Formation in western Maryland and northern West Virginia.

LOYALHANNA AND GREENBRIER FORMATIONS
(Figure 5, columns 1, 3, and 4)

The Loyalhanna Formation is a thin tongue, less than 30 m (100 ft) thick, of the middle Mississippian Greenbrier Group limestone extending across southwestern and central Pennsylvania. The Loyalhanna grades from a sandy limestone in the south to a calcareous sandstone in the north, in most places strikingly crossbedded. A second thin Greenbrier tongue, the Wymps Gap Limestone Member of the Mauch Chunk Formation, is present throughout much of southwest-central Pennsylvania. The Loyalhanna and Wymps Gap merge in southwestern Pennsylvania to form the subsurface Greenbrier Formation, which in turn is traceable into part of the thick Greenbrier carbonate sequence of West Virginia (Adams, 1970).

The Loyalhanna lies directly and possibly disconformably upon the upper surface of the Burgoon Sandstone except in part of north-central Pennsylvania, where an early wedge of the Mauch Chunk Formation intervenes (Wells, 1974).

MAUCH CHUNK FORMATION
(Figure 5, columns 1, 3–6)

The Mauch Chunk Formation is composed of grayish-red shale and siltstone and some light-gray to yellowish-gray sandstone. It is almost entirely nonmarine, containing some plant fossils and fish fragments. Maximum thickness is uncertain but probably is in the 2,450- to 2,750-m (8,000- to 9,000-ft) range.

The lower part of the Mauch Chunk is a facies equivalent of the Greenbrier-Loyalhanna. In southwestern Pennsylvania, the basal Mauch Chunk wedges out between the underlying Loyalhanna and the Wymps Gap Limestone Member of the Mauch Chunk, which converge to form the Greenbrier Limestone of southwesternmost Pennsylvania. In part of north-central Pennsylvania, a tongue of Mauch Chunk red beds underlies the Loyalhanna facies.

The upper Mauch Chunk is also a facies equivalent of the basal Pottsville in the area of the Southern Anthracite field where the two units are interbedded. Whether the Pottsville-Mauch Chunk contact is conformable or disconformable elsewhere has caused considerable controversy, which is discussed in the following section.

The Mauch Chunk is absent because of nondeposition or erosion, or both, throughout northwestern Pennsylvania and adjacent New York, as well as extreme southwestern and northeastern Pennsylvania.

It undergoes considerable facies changes from southwest to northeast before it is cut out erosionally along the margins of the Northern Anthracite field.

MAJOR DISCONFORMITIES IN THE MISSISSIPPIAN AND PENNSYLVANIAN SYSTEMS
(Figure 5, columns 1, 4, and 6)

The formation of two widespread disconformities during the Mississippian and Pennsylvanian Periods has been hypothesized for Pennsylvania and New York. The earlier of these disconformities is believed to have formed on top of the Burgoon Sandstone before deposition of the Loyalhanna Limestone during Meramecian and, perhaps, early Chesterian time (Reger, 1927). The second disconformity, between the basal Pottsville and the underlying Mississippian and uppermost Devonian strata, formed from late Chesterian through early Atokan time.

The existence of the Burgoon-Loyalhanna disconformity is largely based upon the presumed relative ages of the Loyalhanna-Greenbrier (late Meramecian, on the basis of marine invertebrates) and the Burgoon (presumed Osagean at the latest, on the basis of plant fossils). However, the reality of this disconformity is questionable. The contact between the two is sharp but otherwise remarkably uniform. The age of the Loyalhanna is probably fairly reliable, but control on the terminal age of the Burgoon is very weak. We postulate later in this report that the Burgoon Sandstone was deposited on a vast anastomosing alluvial sand plain, which by Meramecian time was depositionally static. If so, the relation between the Burgoon and Loyalhanna is simply that of a transgressive marine unit encroaching on a foundering alluvial plain. However, at the same time, it appears that epeirogenic uplift was beginning in northern Pennsylvania and New York inducing mild erosion of the Lower Mississippian sediments and restricting the northwestward encroachment of the Loyalhanna. The northern source of the sand fraction of the Loyalhanna is believed to be an erosional escarpment of the Burgoon.

The sub-Pottsville disconformity was originally proposed by I. C. White (1891) to explain the absence of certain floral assemblages from the presumed time-sequential Mississippian-Pennsylvanian paleobotanical zonation system. The disconformity was also proposed to explain the northwestward thinning of the Pennsylvanian Pottsville and the progressive northwestward loss of the Mississippian Mauch Chunk Formation and subjacent Mississippian strata.

Only in the Southern Anthracite field (fig. 5, column 5), and in southeastern West Virginia, where the complete floral sequence is present, were the Mauch Chunk (or equivalent in West Virginia) and Pottsville believed to be conformable. North and west from these limited conformable areas, successively older Mississippian strata were believed to have been truncated by erosion during Early Pennsylvanian time. After erosion, Pennsylvanian Pottsville units were deposited in onlap fashion, so that the basal Pennsylvanian became progressively younger to the northwest. In the extreme case in New York, the Lower Pennsylvanian Olean conglomerate rests disconformably upon the uppermost Devonian Oswayo Formation.

There seems to be little doubt that in places where the Pottsville rests upon units older than the Mauch Chunk, a disconformity is required. In at least part of northern Pennsylvania and New York, erosion probably continued from the Meramecian Epoch into the Morrowan or, possibly, the Atokan Epoch. To what extent erosion was continuous during this span of time depends entirely upon how far north Mauch Chunk sediments encroached before being eroded back to their present limit. The lower beds of the Mauch Chunk (excluding the pre-Loyalhanna tongue in north-central Pennsylvania) now extend only a short distance beyond the northern limit of the Loyalhanna. Around its present margin, the Mauch Chunk apears to have been uplifted and eroded back by the Late Mississippian to Early Pennsylvanian epeirogenic activity, but how far this beveling cut the Mauch Chunk back from its original maximum encroachment is unknown. Nor is it clear how far to the southeast this erosional disconformity continues upon the upper surface of the Mauch Chunk.

According to White's classical concept, the disconformity should exist where the lowest Pennsylvanian floral zone disappears. If this concept is true, the disconformity would extend across the entire State, except for the Southern Anthracite field. However, physical observation of the Mauch Chunk-Pottsville contact in other areas has produced doubts about any substantial disconformable break (Ferm and Cavaroc, 1969; Ferm, 1974). Glass and others (1977, p. 14) have suggested that some of the Lower Pennsylvanian floral zones are biofacies equivalents of the Upper Mississippian zone related to the Mauch Chunk Formation. This possibility has been rejected by most paleobotanists on the basis of phylogenetic comparisons between floral suites of the zones involved. It is also possible that the interrelationships between the floral assemblages and the lithostratigraphic units may have been oversimplified, resulting in the misplacing of a lithostratigraphic boundary on a biostratigraphic basis.

POTTSVILLE GROUP
(Figure 5, columns 1–6)

The Pottsville is dominantly sandstone, conglomerate, and siltstone, and has subordinate amounts of coal, shale, and limestone. Thickness of the group is 215 to 460 m (800 to 1,500 ft) in the Southern and Middle Anthracite fields, but only 15 to 85 m (50 to 250 ft) elsewhere in Pennsylvania.

The Pottsville is entirely nonmarine except in western Pennsylvania, where some marine limestone and shale are present in the upper part. Plant fossils are common throughout.

The lower Pottsville is a facies equivalent of the uppermost Mauch Chunk in the area of the Southern Anthracite field and may or may not be conformable with most of the Mauch Chunk elsewhere (see preceding section on "Major Disconformities"). The Pottsville rests disconformably on lower units down to the Upper Devonian Oswayo in northwestern Pennsylvania and southwestern New York, and the Upper Devonian Catskill Formation at the northern end of the Northern Anthracite field.

The Pottsville is thinnest (15 to 40 m, 50 to 130 ft) where it lies directly upon the eroded Burgoon Sandstone, which apparently produced an Early Pennsylvanian topographic high. The unusual Mercer high-alumina flint clays occur at this disconformable Burgoon-Pottsville contact and at a similar contact between the Pottsville and a resistant sandstone in the lowermost part of the Mauch Chunk Formation.

The Pottsville in northwestern and north-central Pennsylvania was derived from the reworking of earlier Paleozoic sediments in New York uplifted around the rim of the North American craton (Fuller, 1955). The source of the remaining Pottsville was the orogenic highlands to the southeast (Meckel, 1967).

LLEWELLYN FORMATION
(Figure 5, columns 5 and 6)

The Llewellyn Formation is a mixture of interbedded conglomerate, sandstone, siltstone, claystone, and coal. The Llewellyn is the lateral equivalent of the Allegheny and Conemaugh Groups of western Pennsylvania, and possibly the Monongahela Group and part of the Dunkard Group as well. In general, the Llewellyn is much coarser grained than the equivalent rocks to the west. Maximum remaining thickness is 1,070 m (3,500 ft). The entire sequence is nonmarine, except for the thin Mill Creek limestone bed in the Northern Anthracite field (Chow, 1951). Plant fossils are common.

ALLEGHENY, CONEMAUGH, AND MONONGAHELA GROUPS
(Figure 5, columns 1–4)

The Allegheny, Conemaugh, and Monongahela Groups are a sequence composed of many beds of sandstone, siltstone, claystone, coal, and limestone. Except locally, no rock type is dominant throughout any substantial part of the section. Subtle differences are found in the proportion of the various rock types as well as changes in secondary characteristics, such as color and presence or absence of marine fossils.

The establishment of these three groups along with the overlying Permian(?) Dunkard Group arose from early recognition that parts of the total post-Pottsville sequence frequently contained mineable coal beds, whereas others did not. The Allegheny and Monongahela have mineable coals and were originally called the "Lower Productive" and "Upper Productive," respectively, whereas the Conemaugh and Dunkard, which contain thin seams, were the "Lower Barren" and "Upper Barren." In effect, these units were defined by a slight change in a secondary characteristic (thickness) of a volumetrically minor lithologic constituent (coal).

Whatever its economic virtue, the use of "coal mineability" as the defining characteristic for formal geologic units was vague and impossible to apply consistently. Recognizing this difficulty, and faced with a lithologically heterogeneous section, 19th century geologists turned to key beds to provide boundary markers for the Allegheny, Conemaugh, and Monongahela Groups. To retain the concept that the Allegheny and Monongahela Groups contained most of the mineable coals, the key beds selected were the lowest and highest coal beds in each unit.

Inasmuch as a key bed must be a single identifiable widespread unit, it has been accepted, more or less on faith, that coal seams do indeed have these necessary characteristics. In reality, only the Pittsburgh coal (the base of the Monongahela Group) has the true continuity expected of a key bed. In practice, the other boundaries of the four groups are correlated generally on the basis of vertical spacing, and by reference to the relative position of a multiplicity of other beds recognized throughout the sequence. Any coal conveniently close to the expected key-bed boundary is used as such, so long as it persists. For obvious reasons, the code of stratigraphic nomenclature (American Commission on Stratigraphic Nomenclature, 1970) cannot be rigously applied to these units.

The Allegheny Group from the base of the Brookville coal to the top of the Upper Freeport coal is persistently about 80 to 100 m (270 to 320 ft) thick. The lower half contains some marine or brackish water units and no freshwater limestone. The upper half is entirely nonmarine and contains freshwater limestone. The Allegheny Group has no redbeds.

The Conemaugh Group lies between the top of the Upper Freeport coal and the base of the Pittsburgh coal; it is divided into two formations at the top of the Ames marine zone. The lower formation (Glenshaw) contains four widespread marine zones. The upper formation (Casselman) is entirely nonmarine except for a limited brackish-water zone in the lower part. The Conemaugh Group ranges from less than 170 m (550 ft) in Washington County, to more than 275 m (900 ft) in Somerset County. It contains scattered redbeds and nonmarine limestones throughout; several marine limestone units occur in the Glenshaw Formation.

The Monongahela Group extends from the base of the Pittsburgh coal to the top of the Waynesburg coal, and is 85–115 m (275–375 ft) thick in Pennsylvania, increasing from west to east. It is entirely nonmarine, contains abundant freshwater limestone, and has no redbeds.

BIOSTRATIGRAPHY

Marine units containing the principal faunal suites are largely confined to the Devonian-Mississippian Riceville-Oswayo through "Hempfield" sequence; the Mississippian Loyalhanna-Greenbrier sequence; and the Pennsylvanian lower Allegheny Group and Glenshaw Formation. Marine units are mostly limited to western Pennsylvania. (See figs. 4 and 5.) Except for a few thin marine tongues, all the remaining Mississippian and Pennsylvanian is nonmarine, and the associated fauna is sparse and poorly understood.

Fossil plants are common in the Pennsylvanian sequence, and the interrelations between the Pennsylvanian flora and fauna are fairly well understood. Plant fossils occur sporadically throughout the nonmarine Mississippian sequence but only rarely in close association with any marine fauna.

PALEOZOOLOGY

In 1948, Cooper (p. 256) commented on the paleontologic aspects of the Mississippian System in the central and northern Appalachians: "The stratigraphic work upon which the succession was divided into formations was almost entirely of a physical character, and it has been carried on in a near-vacuum of systematic paleontology. Thus many regional correlations are inaccurate." In 1979, that statement regarding the Mississippian of Pennsylvania is still valid. A similar but less harsh commentary is applicable to the present status of paleozoologcal research in the Pennsylvanian System of this part of the Appalachian region.

Although adequate paleontological studies of the Mississippian are lacking, the singularly important contributions on this subject by Caster (1930, 1934) and Chadwick (1935) should be recognized. Caster's documentation of Late Devonian and Mississippian invertebrates of northwestern Pennsylvania, along with his pioneering formulation of facies concepts still stands today as the standard biostratigraphic reference for that area.

Because of the complex facies patterns and lateral intergradations discussed by Caster (1934) and herein under "Lithostratigraphy," and because of the necessarily voluminous systematic paleontology yet to be accomplished, a biostratigraphic zonation of the Lower Mississippian marine sequence has not been established. Considerable effort has been directed at establishing the position of the Mississippian-Devonian boundary (Caster, 1934; Chadwick, 1935; Holland, 1958), and consideration has been given to the possibility that many faunal elements may overlap and approximate a gradation (Caster and others, 1935). Caster's invertebrate faunal lists (1934) tell little of actual abundances of the various taxa, but some inferences can be made regarding diversity changes from Devonian to Mississippian. In the Mississippian, there appear to be significant diversity increases amongst strophomenid and spiriferid brachiopods, along with increases of diversity amongst archaeogastropods, particularly the trochinids.

Holland (1958) described 47 species, subspecies, and morphological variants of brachiopods in the Oswayo and Knapp Formations. He concluded that only two species crossed the Oswayo-Knapp boundary (1958, p. 71) in the Bradford-Warren area. The systemic boundary is there placed at the horizon having the greatest number of new brachiopod forms. Chief among these brachiopods are the genera *Dictyoclostus* and *Syringothyris*. Holland (1958, p. 71) admitted that facies may be a controlling factor in the distribution of brachiopods across the Devonian-Mississippian boundary. This points up the requirement that detailed paleobiogeographic and paleoecologic studies should go hand-in-hand with systematic descriptions of the fossils. Williams (1903) long ago emphasized the importance of understanding the shifting of faunas with depositional environments. His examples were drawn from the Upper Devonian of northern Pennsylvania and southern New York. The principles he articulated are equally applicable to the Devonian-Mississippian sequence of northwestern Pennsylvania today.

Sass (1960) affirmed the Kinderhookian age of the Corry Sandstone in Pennsylvania and pointed out that correlation with the Berea Sandstone to the west is based on stratigraphic position rather than faunal evidence. He suggested (1960, p. 296) that the lower member of the Corry may well correlate with the upper part of the Bedford Shale of Ohio but that systematic studies of Bedford faunas are still needed. Sass also recognized the influence of environments on the invertebrates, citing the more common rugose brachiopod species in the eastern part of the Corry as evidence of more nearshore conditions (1960, p. 295). On the basis of paleobotanical evidence, conodont zonation, and regional lithostratigraphic correlations, deWitt (1970) concluded that the basal Bedford shale may be very Late Devonian in Ohio and Kentucky but that the remaining Bedford Shale and Berea Sandstone are Early Mississippian.

In southwestern Pennsylvania, emphasis has also been placed on locating the Mississippian-Devonian boundary rather than on biostratigraphic zonation. Laird (1941, 1942) listed invertebrates collected from the Devonian and Mississippian strata exposed in the anticlinal inliers of Fayette County. He said (1941, p. 18) that the occurrence of certain species of *Syringothyris*, *Eumetria*, *Leptodesma*, and *Palaeoneilo* mark the base of the Mississippian. The disappearance of certain species of what is now *Cyrtospirifer* ("*Spirifer disjunctus*" gens) marks the upper limit of the Devonian System.

In 1943, Busch (p. 154) examined invertebrates in a shale interval in the upper part of the Shenango Formation in the Oil City 15-minute quadrangle in northwestern Pennsylvania. He concluded, on the basis of comparison with invertebrates of the Mississippi Valley, that the interval could be assigned to a series no older than middle Meramecian. Weller and others (1948, p. 160) questioned Busch's identifications and seriously questioned his correlation. They mentioned that strata overlying the Cuyahoga in Ohio are not known to be younger than uppermost Osagean. Szmuc (1970, p. 47) considers the Shenango fauna in northeastern Ohio to bear a close affinity to that of the eastern part of the Meadville Formation (Cuyahoga Group).

Other than what has been accomplished by Chadwick and by Caster and his students at Cincinnati, and what was done before the turn of the century by the Second Pennsylvania Survey, very little work has been directed toward the paleozoology of the Lower Mississippian of Pennsylvania. Recent work on trace fossils in the Devonian and Mississipian of northwestern Pennsylvania by Gutschick and Lamborn (1975) points to a whole new avenue of biostratigraphic analysis. Another avenue may be opened through conodont studies.

The Upper Mississippian (Meramecian through Chesterian) is represented in Pennsylvania mainly by the Mauch Chunk Formation, which is dominantly nonmarine and rarely bears an invertebrate fauna. In the southwestern part of the State, where the Greenbrier limestones intertongue with the Mauch Chunk redbeds, some paleozoological insights have been obtained. Benson (1934) identified some brachiopods from a Greenbrier tongue near Uniontown, Pa., and concluded that the brachiopod fauna is similar to those of the Greenbrier Formation of West Virginia and the Ste. Genevieve Limestone of Kentucky. Haney (1963, p. 198–199) described the Greenbrier fauna of Pennsylvania as a principally brachiopod-crinoid assemblage closely related to the fauna of the Batesville Sandstone of Arkansas. He regards the Greenbrier fauna as a late Meramecian to early Chestrian assemblage.

In his study of the Mauch Group in northwestern West Virginia, Busanus (1974, 1976) identified an assemblage characterized by pelmatozoans and articulate brachiopods from the Wymps Gap Limestone tongue of the Greenbrier. Because most of the forms identified in the Mauch Chunk-Greenbrier transition are relatively long ranging, Busanus (oral commun., 1978) does not believe that an Elviran (Late Chesterian) age for that part of the section can be refined.

The Wymps Gap Limestone in Somerset County, Pa., as delineated by Flint (1965, p. 48), is somewhat above the base of the Chesterian Series. Another limestone called the "Deer Valley" directly overlies the Loyalhanna Limestone and is considered as basal Chesterian, but Flint (1965, p. 49) recommended further stratigraphic and paleontologic studies.

The Mississippian-Pennsylvanian boundary is marked by a clear unconformity over a large part of Pennsylvania, as has been discussed under "Lithostratigraphy" above. Where the Mauch Chunk and Pottsville are interbedded, the systemic boundary is picked with varying degrees of confidence by paleobotanical methods. Some potential for paleozoological definition of the Mississippian-Pennsylvanian boundary in Pennsylvania may be found in the detailed study of freshwater arthropods and bivalves, but to date, no such research has been done.

Raymond (1911, p. 95–96) presented a list of invertebrates found in the Vanport marine zone of the Pennsylvanian Allegheny Group, along with invertebrates in five marine zones of the Conemaugh Group. His list was preliminary, and no accurate biostratigraphic correlations could be made from it. Williams (1960) identified a large fauna from the Pottsville and Allegheny Groups of western Pennsylvania and established the beginnings of proper paleozoological zonation within those groups. He (Williams, 1960, p. 911) explained the necessary paleoecological and paleoenvironmental evaluations that are a prerequisite to accurate zonation and correlation.

The Glenshaw Formation of the Conemaugh Group is characterized by several marine "zones," which may be genuine fossiliferous limestone beds or which may grade laterally to highly fossiliferous, carbonaceous, calcareous siltstone. The best known and most widespread of these units are the Brush Creek, the Cambridge (Pine Creek), and the Ames. The Ames marine zone is used as a key bed to mark the top of the Glenshaw Formation. Over much of their extent, these marine units may be true biostromes. Invertebrate faunal diversity appears to be greater in these marine zones than at any other horizon within the Mississippian or Pennsylvanian. Seaman (1940, 1941, 1942) listed a large number of invertebrates from these three marine zones and pointed out some minor differences between the three suites, but he did not attempt to erect biozones or to establish correlations with the midcontinent. Chow (1951) documented the occurrence of a marine zone in the Llewellyn Formation called the Mill Creek Limestone; correlation with the Ames of western Pennsylvania is based on interval and faunal content. Further studies on the Glenshaw marine units have been carried out by Lintz (1958), Murphy (1970), Rollins and Donahue (1971), Shaak (1972), and Donahue and Rollins (1974). The thrust of recent research and investigation with regard to the Glenshaw marine intervals has been more to recognize and define fossil invertebrate communities and their ecosystem dynamics through time and in relation to sedimentation cycles (Shaak, 1972; Rollins and Donahue, 1975). Paleontological zonation by invertebrates in this part of the Carboniferous will be contingent upon the success of these paleoecological investigations.

The upper part of the Conemaugh Group, the Casselman Formation, is for the most part nonmarine, and relatively little paleozoological information has been derived from these rocks. The overlying nonmarine Monongahela Group has to date also yielded relatively little paleozoological data. Durden (1969) has provided an important avenue for zonation and correlation through his research on blattoid insects in these nonmarine strata, as well as in the underlying Allegheny and Pottsville Groups and the laterally equivalent Llewellyn Formation.

Fossil vertebrates (fish) have been collected by various workers from all of the Carboniferous of Pennsylvania, but the most serious research on this topic has been carried out by Lund (1970). Continued detailed studies of fossil fishes may well provide a basis for zonation of the upper Conemaugh and Monongahela Group.

PALEOBOTANY

The floral biostratigraphy of Pennsylvania was investigated with considerable energy in the late 19th and early 20th centuries, but interest has dwindled since, so that only a few poorly supported workers continue, intermittently, to pursue the subject. The most authorative summary of the floral biostratigraphy of the entire Mississippian-Pennsylvanian was given in Read and Mamay (1964). Darrah (1969) produced an extensive review of the Late Pennsylvanian flora. The floral biostratigraphic sequence shown in figure 11 is based mostly on Read and Mamay (1964).

The 12 Mississippian and Pennsylvanian floral zones shown in figure 11 are considered biostratigraphically and chronologically sequential. At no single place in Pennsylvania, however, is the complete sequence found. The absence of zones 7 and 8 in the Southern and Middle Anthracite fields is probably a matter of nonpreservation or locally unsuitable growth environment, rather than a missing stratigraphic section. (See Wood and others, 1969, p. 79.

North and northwest from the Southern Anthracite field, Lower Pennsylvanian floral zones 4, 5, 6, and 7 disappear, as do Mississippian zones 3 and 2. This expanding gap in the floral sequence was explained by White (1891) as the result of widespread erosion at the end of the Mississippian, which successively removed the Mississippian sequence toward the northwest. Subsequently, onlapping sediments of the Lower Pennsylvanian Pottsville sequence advanced slowly across this erosion surface. The lowest Pottsville becomes progressively younger toward the northwest, and the older Pennsylvanian

FLORAL ZONE (READ AND MAMAY, 1964)	DOMINANT CHARACTERISTIC FLORAL SPECIES (READ and MAMAY, 1964)	PENNSYLVANIA EXCEPT SOUTHERN and MIDDLE ANTHRACITE FIELDS	SOUTHERN AND MIDDLE ANTHRACITE FIELDS	SERIES	SYSTEM
13	*Callipteris* spp.	Dunkard Group	Possibly present in uppermost Llewellyn Formation	Wolf-campian	Permian
12	*Danaeites* spp.	Upper Monongahela Group	Possibly present in upper Llewellyn Formation.	Virgil-ian	Pennsylvanian
11	*Lescuropteris* spp.	Lower Monongahela Group and Casselman Formation of Conemaugh Group	Possibly present in upper Llewellyn Formation	Miss-ourian	Pennsylvanian
10	*Neuropteris flexuosa* and *Pecopteris* spp.	Glenshaw Formation of Conemaugh Group and upper Allegheny Group	Lower Llewellyn Formation	Miss-ourian	Pennsylvanian
9	*Neuropteris rarinervis*	Lower Allegheny Formation	Upper Sharp Mountain Member of Pottsville Formation and possibly lowermost Llewellyn Formation	Des Moinesian	Pennsylvanian
8	*Neuropteris tenuifolia*	Upper Pottsville Formation (Mercer)	Not known. Presumed equivalent to middle Sharp Mountain Member of Pottsville Formation	Des Moinesian	Pennsylvanian
7	*Megalopteris* spp.	Middle Pottsville Formation (Connoquenessing)	Not known. Presumed equivalent to lower Sharp Mountain Member of Pottsville Formation	Atokan	Pennsylvanian
6	*Neuropteris tennesseeana* and *Mariopteris pygmaea*	Lowest Pottsville Formation in NW. Pa. (Sharon). Absent elsewhere by disconformity (nondeposition) and/or biofacies with zone 3	Schuylkill Member of Pottsville Formation	Morrowan	Pennsylvanian
5	*Mariopteris pottsvillea* and *Aneimites* spp.	Absent by disconformity (nondeposition) and/or biofacies with zone 3	Upper Tumbling Run Member of Pottsville Formation	Morrowan	Pennsylvanian
4	*Neuropteris pocahontas* and *Mariopteris evemopteroides*	Absent by disconformity (nondeposition) and/or biofacies with zone 3	Lower Tumbling Run Member of Pottsville Formation	? Morrowan ? Chesterian ?	? Pennsylvanian ? Mississippian ?
3	*Fryopsis* spp. and *Sphenopteridium* spp.	Mauch Chunk Formation. Absent in SW. Pa. (marine facies) and northern Pa. (Disconformable nondeposition and erosion)	Mauch Chunk Formation	Chesterian	Mississippian
2	*Triphyllopteris* spp.	Burgoon and upper Pocono Formations. Absent in northern Pa. by disconformable nondeposition and erosion	Upper Pocono Formation	Mera-mecian / Osag-ean	Mississippian
1	*Adiantites* spp.	Upper Huntley Mountain, upper Rockwell, and lower Pocono Formations	Upper Spechty Kopf and lower Pocono Formations	Kinder-hookian	Mississippian

FIGURE 11.—Mississippian and Pennsylvanian floral zones.

floral zones disappear. See the section on "Major Disconformities of the Mississippian-Pennsylvanian" for additional discussion of this subject.

CHRONOSTRATIGRAPHY

The time boundaries of the Mississippian and Pennsylvanian Periods and their subordinate epochs (fig. 5) are placed entirely by reference to the biostratigraphy of the rock sequence. No supplementary physical data, such as radioactive dating, are available.

Of the three period boundaries involved, only the Devonian-Mississippian boundary in the marine section of northwestern Pennsylvania, and the boundary marked by the disconformity between the Pennsylvanian Pottsville and Lower Mississippian Burgoon (or older strata) are located with some reasonable precision. The extension of the Devonian-Mississippian boundary eastward into the dominantly nonmarine Huntley Mountain, Rockwell, and Spechty Kopf Formations is primarily based upon interval and some general control from the plant fossils.

The Pennsylvanian-Mississippian boundary in the Southern Anthracite area, where the Pottsville reaches maximum thickness, may be placed arbitrarily at the base of that unit. Because, however, the upper Mauch Chunk is the lateral facies equivalent of at least part of the Pottsville, the period boundary must pass into the Mauch Chunk at some point. Because there is some doubt as to what extent the Pottsville-Mauch Chunk contact is conformable or disconformable elsewhere, the position of the Pennsylvanian-Mississippian boundary is obscure.

The least clear of the three period boundaries is that between the Pennsylvanian and Permian. The problem is inordinately complex. The most exhaustive examination of the location of the Pennsylvanian-Permian boundary is in "The Age of the Dunkard" (Barlow, 1975), a symposium in which 23 paleobotanical and paleozoological specialists discuss the problem. Opinions range from placing the Permian-Pennsylvanian boundary as low stratigraphically as the Casselman Formation of the Conemaugh Group, to above the uppermost occurrence of the Dunkard. Much simplified, the problem centers about whether or not the first occurrence of the Permian index fossil, *Callipteris conferta* in the Appalachians corresponds chronologically with its first occurrence in the Permian standard section in central Europe.

The epoch boundaries within the Carboniferous of Pennsylvania are poorly defined, except for those of the Desmoinesian and, in western Pennsylvania, the Missourian.

DEPOSITIONAL HISTORY

Sediments of the Mississippian and Pennsylvanian Periods were deposited upon the vast Upper Devonian Catskill deltaic complex. These sediments were derived from the southeastern orogenic uplift, which had formed along the impact margin of the North American and African continental plates, and also from the edge of the North American cratonic heartland and the older Taconic impact area to the north and northeast.

The Catskill deltaic complex achieved maximum westward progradation during the late part of the Late Devonian (Chautauquan) (fig. 12A). Shortly before the end of that period, a widespread and relatively abrupt marine transgression terminated the Catskill deltaic complex, overrunning its upper surface by 80–160 km (50–100 mi) and depositing the Riceville Shale and Oswayo Formation (fig. 12B). Some thin marine tongues advanced briefly as far east as Clinton and Bedford Counties. The effects of the transgression were such that even the equivalent nonmarine Huntley Mountain, Rockwell, and Spechty Kopf Formations lost most of the typical Catskill characteristics, notably most of the distinctive red coloration. The presence of some possible glaciolacustrine sediments in the Spechty Kopf and Rockwell (Sevon, 1969, 1973) suggests a more severe climate and the presence of glaciers in the orogenic highlands to the east.

During Early Mississippian (Kinderhookian) time (fig. 12C), some westward progradation took place, but, in general, a fairly stable coastal plain was established, dominated by delta-lobe development (Demarest, 1946; Pepper and others, 1954). This episode was followed by the westward extension of the elongate anastomosing alluvial-deltaic Burgoon sand plain during early middle Mississippian (Osagean) time (fig. 12D.)

Three notable changes in the depositional environment were introduced, more or less simultaneously, in middle-Late Mississippian (Meramecian) time (fig. 12E). Mild epeirogenic uplift across northwestern Pennsylvania and adjacent New York ended deposition in that area and initiated some erosion of the Burgoon and equivalents and of older rocks. Similar upwarping probably affected extreme northeastern Pennsylvania. In southeastern Pennsylvania, strong sediment influx initiated redbed deposition of the Mauch Chunk delta. Between the northwestward-prograding Mauch Chunk delta and the upwarped area in the northwest, a shallow restricted embayment penetrated as far as Sullivan County, depositing the Loyalhanna calcareous sandstone, a lateral equivalent of the Greenbrier marine carbonate sequence of West Virginia (Adams, 1970; Wells, 1974). Influx of sand streaming off the wasting Burgoon to the north introduced a strong sand fraction to the Loyalhanna. Similarly, red clastic material from the advancing Mauch Chunk delta gave the Loyalhanna facies a strong red cast in places.

During the Late Mississippian (Chesterian) and Early Pennsylvanian (early Morrowan) time, the Mauch Chunk encroached northwestward, squeezing out the Greenbrier-Loyalhanna embayment except in extreme southwest Pennsylvania (fig. 12E). The Mauch Chunk apparently encroached across the uplifted northwest area for some unknown, but probably limited, distance before continued uplift resulted in erosion of the Mauch Chunk margin and further wearing away of the Burgoon and lower strata. The Mauch Chunk itself was overrun from the southeast by the course alluvial clastic material of the Tumbling Run and Schuylkill Members of the Pottsville Formation.

By Early-Middle Pennsylvanian (late Morrowan-Atokan), Pottsville alluvial clastic deposits from the southeast orogenic source had spread across all but the northwest quarter of Pennsylvania and adjacent New York (fig. 13A). Renewed Pottsville alluvial influx from the fringes of the North American craton spilled across New York and northwestern Pennsylvania. The northwest and southeast Pottsville clastic deposits merged, burying almost all older rocks. In a narrow band across Jefferson, Clearfield, Centre, and Clinton Counties, however, a cuestalike erosional remnant of the Burgoon Sandstone (and, locally, a similar remnant of a lower Mauch Chunk sandstone) stood high enough to escape burial (fig. 13A). Along the crest of these sandstone ridges, the unusual Mercer high-alumina flint clays formed (Edmunds and Berg, 1971, p. 57–61).

A general marine transgression during Middle Pennsylvanian (early Desmoinesian) produced a shallow marine embayment across west-central Pennsylvania surrounded by lower and upper delta-plain and alluvial-plain environments (fig. 13B) (Ferm, 1974; Ferm and Cavaroc, 1969). The associated sediments of the upper Pottsville and lower Allegheny Groups in the west, and the upper Sharp Mountain and lower Llewellyn Formations in the east are typically complex and variable.

By late Desmoinesian time, the sea had withdrawn westward into Ohio, allowing deposition of the entirely nonmarine upper Allegheny Group and lower quarter of the Glenshaw Formation in Pennsylvania (fig. 13) (Ferm, 1974).

Widespread marine invasions spread across western Pennsylvania during early Missourian time, reintroducing the shallow marine and lower delta-plain sediments associated with the upper three-quarters of the Glenshaw Formation (fig. 13D) (Donahue and Rollins, 1974; Morris, 1967). One of these brief marine transgressions, represented by the Mill Creek Limestone (Chow, 1951), went as far east as Wilkes-Barre, the most easterly marine penetration since early Late Devonian.

The sea withdrew completely and permanently by late Missourian to early Virgilian time, leaving Pennsylvania almost isolated at the extreme northeastern end of a very restricted estuary. The Casselman Formation was deposited as alluvial-deltaic sediments along the estuary margin.

By late Virgilian time, the northeastern end of the Appalachian basin is believed to have been totally severed from any marine connection, and a widespread lake or system of lakes formed, receiving the Upper Pennsylvanian Monongahela Group sediments, as well as those of the succeeding Permian(?) Dunkard Group (fig. 13F) (Berryhill and others, 1971; Donaldson, 1969, 1974).

The sedimentological origin of the Pennsylvania coal-bearing sequence has been the object of intense speculation for well over a century. Early studies attributed a high degree of lateral persistence to various thin lithosomes found in the Pennsylvanian sequence, most particularly to the coal beds (Rogers, 1858; Lesley, 1879). The concept of coal bed persistence was raised to the level of official dogma when the boundaries of the lithostratigraphic subdivisions of the Pennsylvanian were formally defined by key bed coals.

In the late 1920's, a standardized repetitive sequence of rock types, called the cyclothem, was devised for the Pennsylvanian of the midcontinent (Wanless, 1931). The cyclothem concept called for strong lateral continuity of the individual rock types and, by inference, cyclic repetition of widespread depositional environments, caused and controlled by basinwide geological phenomena. Local geological phenomena were relegated to the minor role of "disrupters" of what would otherwise have been a "normal complete" cyclothem. In the central Appalachians, coal seams and other rocks had long been presumed to be thin but enormously widespread lithosomes; the cyclothem concept suddenly promised to provide the long-desired theoretical foundation for the assumption of widespread lateral continuity of lithosomes. Only Ashley (1931) tended

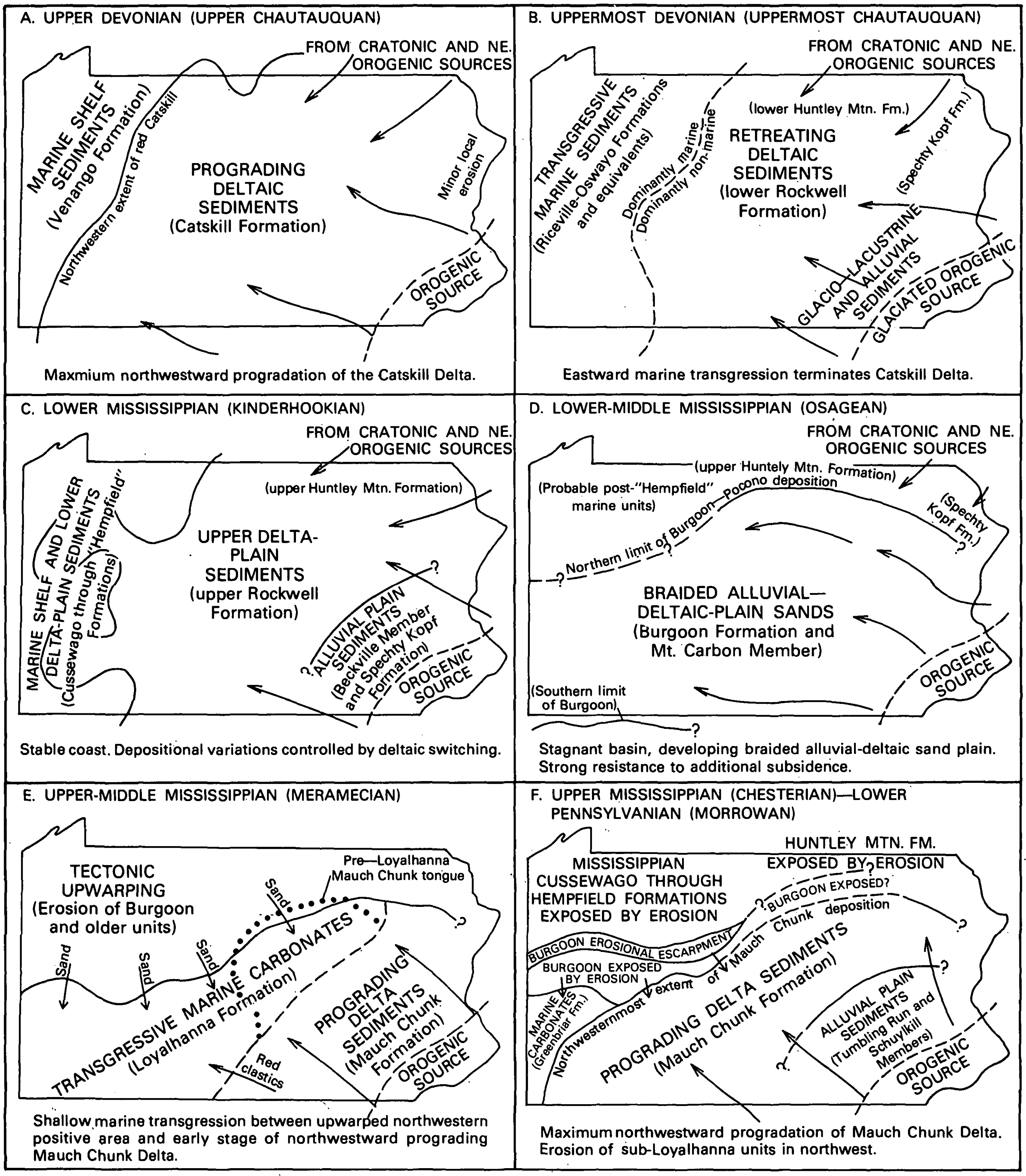

FIGURE 12.—Upper Devonian, Mississippian, and Pennsylvanian paleogeography and depositional environments.

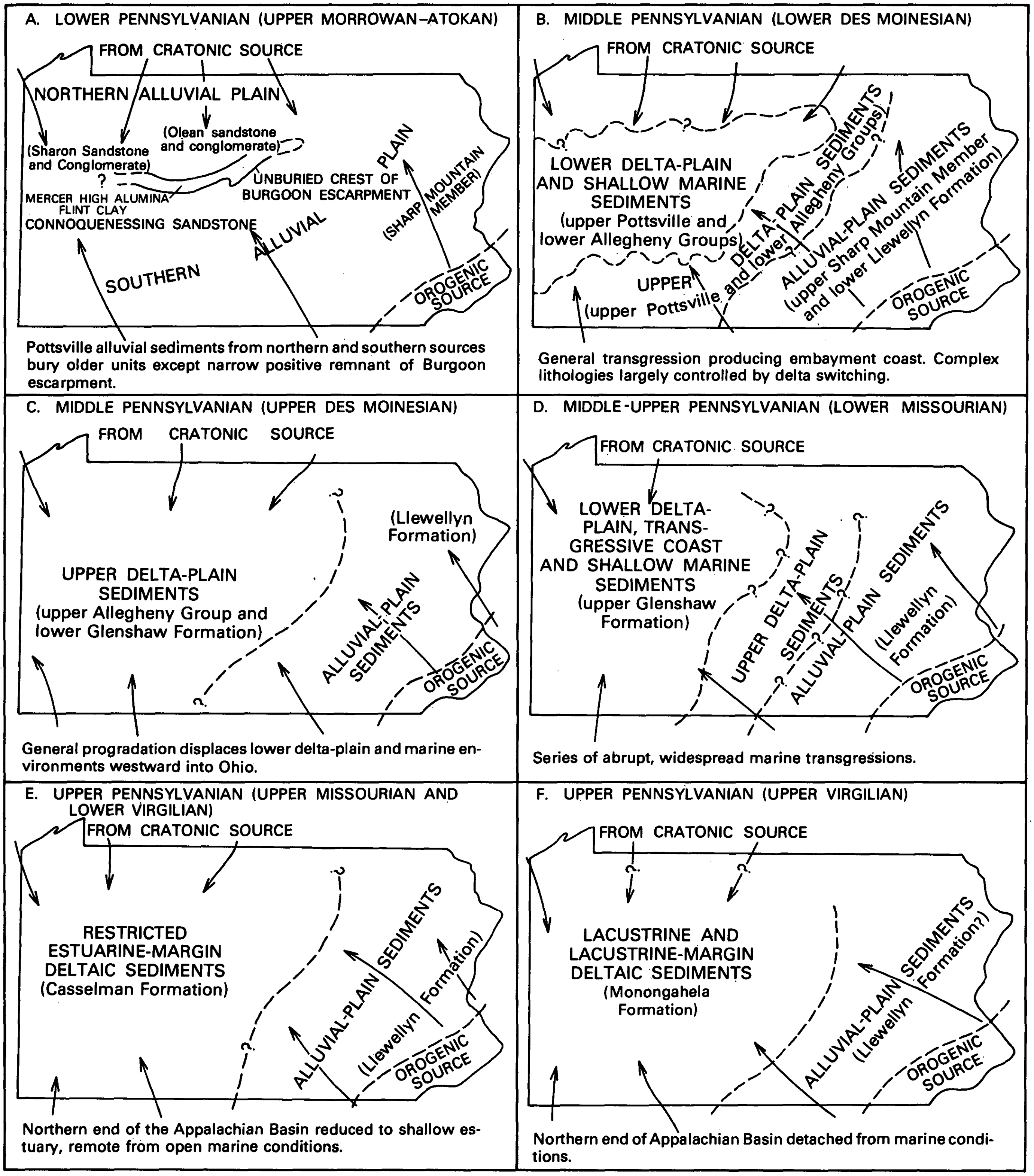

FIGURE 13.—Pennsylvanian paleogeography and depositional environments.

to reject the existence of a detailed Appalachian cyclothem.

Decades were spent trying to fashion the Appalachian cyclothem or cyclothems (Stout, 1931; Reger, 1931; Beerbower, 1961; Branson, 1962; Sturgeon and others, 1958). Eventually, it became apparent that no single cyclothem or reasonably small number of cyclothems could be devised for the Pennsylvanian of the central Appalachians, because of the very limited vertical or lateral lithic continuity.

In the past 30 years, a huge body of fact and theory has evolved dealing with sediments and processes of modern coastal plains. The application of these concepts (Ferm, 1974; Donaldson, 1974) to the Pennsylvanian rocks of the central Appalachians has provided the key to understanding the Pennsylvanian sequence in all its lithologic complexity and variability without resorting to oversimplification.

It seems reasonably certain that the deposition of individual Pennsylvanian lithosomes is not controlled entirely by basinwide agencies, but rather by relatively local conditions of sedimentation having relatively little areal extent and even less temporal persistence. Basinwide sedimentation controls are only overprinted on dominantly local controls. Basinwide geological phenomena did produce most of the gross character of the Pennsylvanian, or large parts of it, such as: the general presence or absence of redbeds, marine units, or freshwater limestones; the average thickness of coal beds; and the overall coarseness of the clastic fraction. Basinwide phenomena did not, however, dictate the lithology or vertical and horizontal arrangement of individual lithosomes.

ECONOMIC GEOLOGY

COAL

Coal fields.—Pennsylvania, which is at the northern end of the Appalachian coal basin, has about 39,000 km^2 (15,000 sq mi) that is underlain by one or more coal beds.

Geographically, the coal-bearing areas of Pennsylvania can be divided into the following fields (fig. 14):

1. Main Bituminous field.
2. George Creek (Wellersburg) field.
3. Broad Top field.
4. North-Central fields (five small fields).
5. Northern Anthracite field.
6. Western Middle Anthracite field.
7. Eastern Middle Anthracite field.
8. Southern Anthracite field.

More than 90 percent of current production comes from the Main Bituminous field.

Rank and heat value.—Pennsylvania coal ranges in rank from high-volatile bituminous to anthracite; rank increases from west to east (fig. 15). Fixed carbon content ranges from 55 to 97.5 percent (dry, ash-free proximate analysis)

On a dry, ash-free basis, the heat value of Pennsylvania coal increases from an average low of about 8,200 cal/g (14,700 Btu/lb) in Beaver and Lawrence Counties to an average maximum of 8,800 cal/g (15,800 Btu/lb) in northern Somerset and southern Cambria Counties, and in the Broad Top and Georges Creek fields. From this high, the heat value decreases with increasing rank to a minimum of about 8,000 cal/g (14,400 Btu/lb) in Carbon County. Mined coal on an as-received basis will generally yield 550 to 1100 cal/g (1,000 to 2,000 Btu/lb) less than the dry, ash-free value.

Sulfur content.—Although the sulfur content of Pennsylvania coal can vary widely for any one seam, even on a local scale, the following two generalizations apply: (1) the average sulfur content of coal seams increases westward, and (2) the stratigraphically lower mineable coals tend to contain more sulfur. In both generalizations, the high concentration of sulfur is related to the brackish to marine depositional environment interpreted for the overlying clastic sediments.

Most coal in the anthracite fields contains 0.5 to 1.5 percent sulfur. The Pennsylvania anthracite fields represent one of the largest reserves of low-sulfur coal in the Eastern United States.

Main Bituminous field coal is mostly high-sulfur (more than 2 percent S), perhaps 5 to 10 percent of the coal is low-sulfur (less than 1 percent S), and 25 to 30 percent is medium-sulfur (1 to 2 percent S). Much of the low-sulfur reserves are concentrated in the Pittsburgh seam.

The small reserves of the Georges Creek and Broad Top fields are medium-sulfur; those of the North-Central fields are low- to medium-sulfur.

Coking potential.—Except for minor nonbanded varieties, all Pennsylvania coal cokes to a degree expected of its rank. That is, the bituminous coal cokes well, and the anthracite and semianthracite coal cokes poorly, or not at all.

Bituminous coal usually has a free swelling index of 5 to 9 and an agglutinating value of 6.5 to 11.0. Most medium- and high-volatile bituminous coal contracts upon coking, whereas low-volatile bituminous coal expands strongly. The low-volatile coal is especially valuable for upgrade blending with more abundant high-volatile coal.

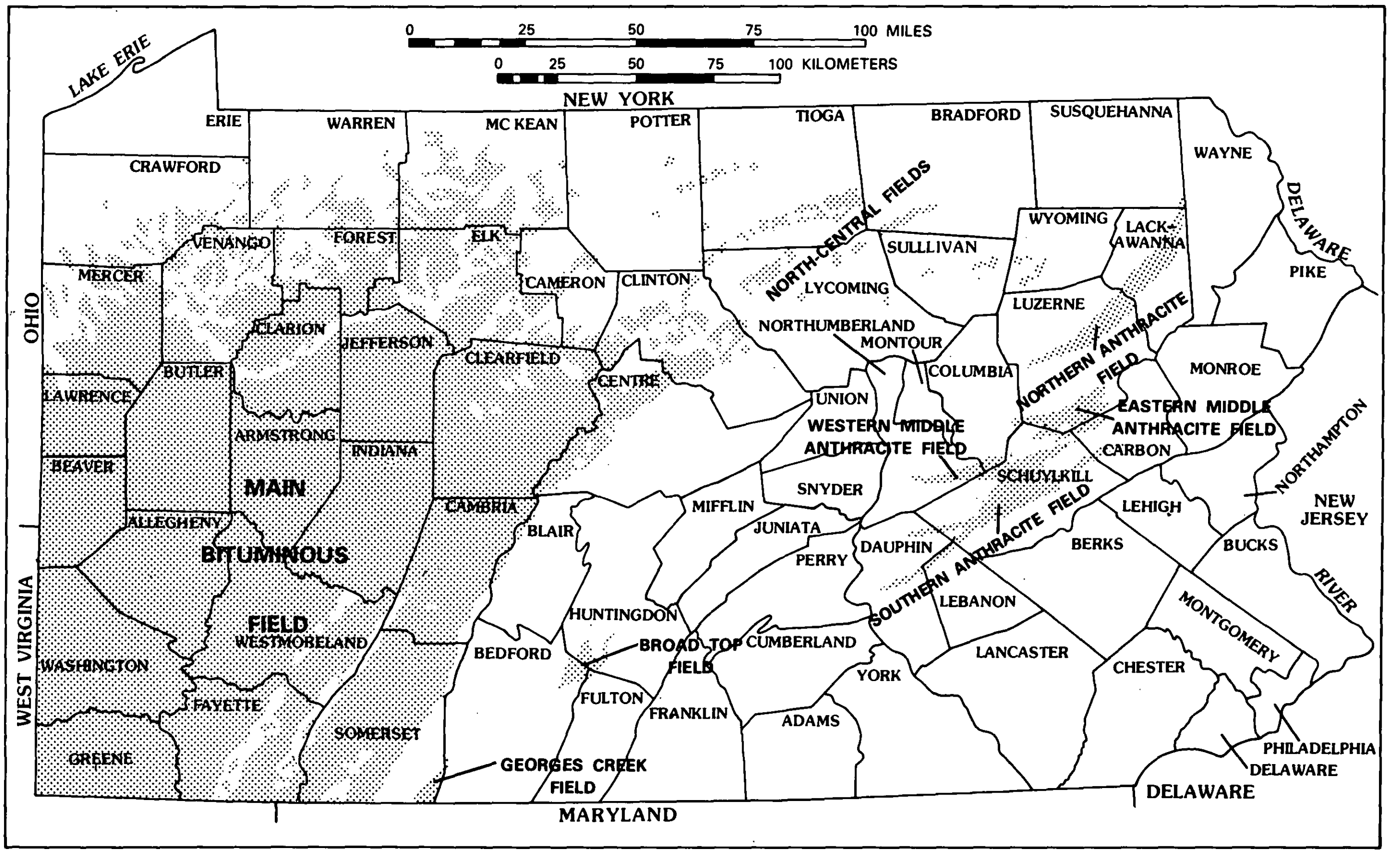

FIGURE 14.—Coal fields of Pennsylvania.

Results of ASTM coke strength tests indicate that Pennsylvania coals behave as would be expected of their rank, although individual samples may vary considerably. If properly blended, most Pennsylvania coke will have adequate strength.

On an as-received and as-carbonized basis, Pennsylvania coal usually produces the following percentage of coking products: coke—66 to 81 percent, gas—10 to 17 percent, tar—2 to 9 percent, and ammonium compounds—4 to 10 percent. The percentage of coke increases and the percentage of other products decreases with increasing rank.

High sulfur content is the persistant detrimental factor in the use of Pennsylvania coal for coking purposes.

Anthracite, semianthracite, and nonbanded bituminous coal are nonagglomerating and noncoking. A small amount of anthracite is used in some coke blends and in foundry coke.

In 1975, Pennsylvania produced 26 million tons of coal for coke manufacture, largely from Washington, Greene, Allegheny, Westmoreland, and Cambria Counties.

Mining and production.—In 1976, 820 mining companies in Pennsylvania produced 85,591,169 t (metric tons) (91,039,650 short tons) of coal from 2,038 mines. Of this total, 29 companies and affiliates produced 41,595,051 t (45,849,925 short tons) or about 50 percent. Table 1 summarizes coal production for 1976.

Resources.—The estimated recoverable coal resources of Pennsylvania as of January 1, 1970, are summarized in table 2 (Edmunds, 1972). Production since January 1, 1970, has been about 32 million t of anthracite and 650 million t of bituminous.

In-place coal resources for Pennsylvania are approximately 57 billion t of bituminous in beds more than 46 cm (18 in.) thick and 15 billion t of anthracite in beds more than 61 cm (24 in.) thick.

Coal-seam correlations.—All significant coal

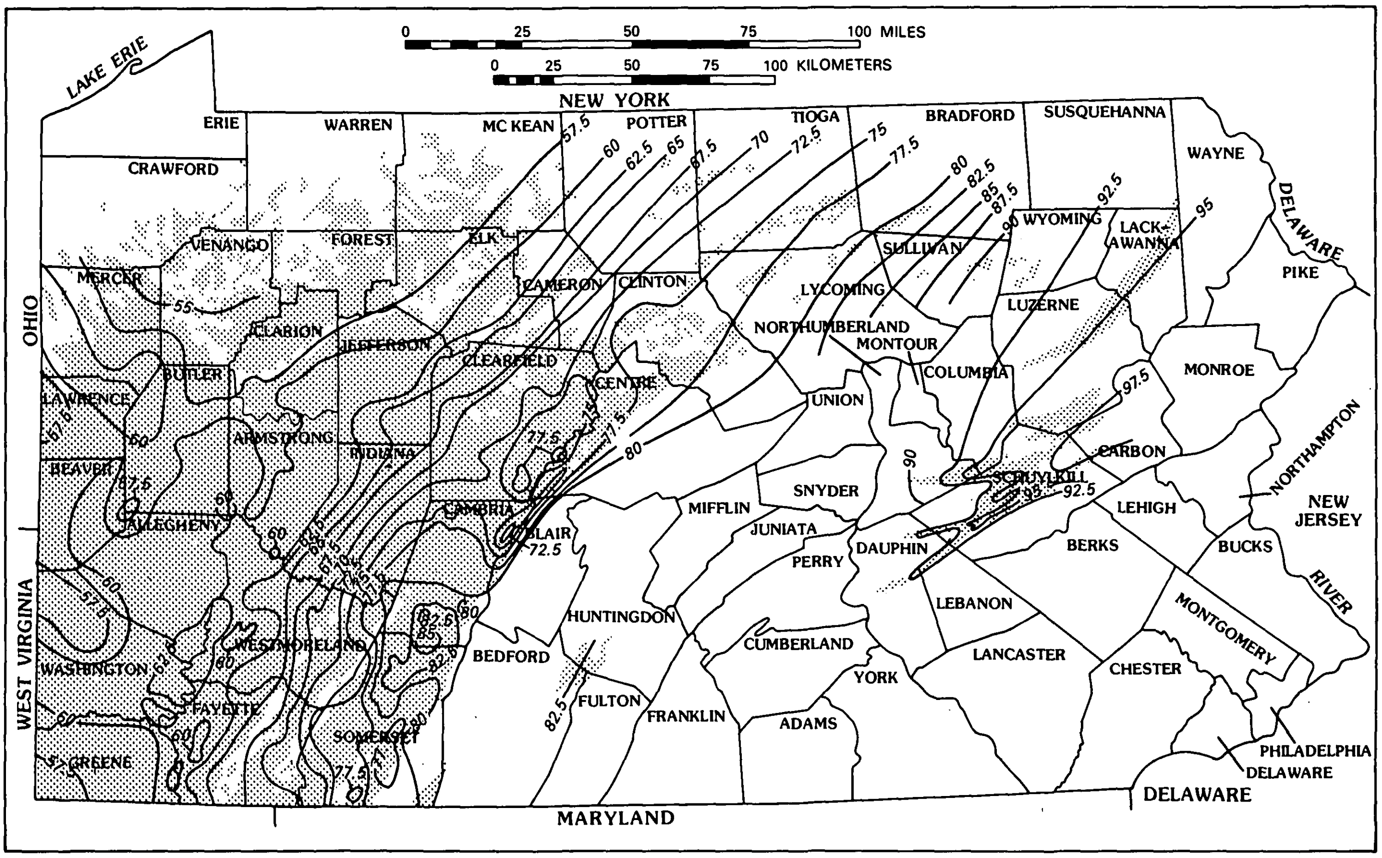

FIGURE 15.—Isocarb map of Pennsylvania.

seams of Pennsylvania are of Pennsylvanian-Permian age and thus are broadly equivalent throughout the State. The lowest (Lykens) coals of the Southern and Western Middle Anthracite fields are somewhat older (Morrowan) than any other coal in the State, and the highest Permian coals in the southwest corner of the Main Bituminous field are the youngest.

Many of the difficulties in determining the properties and extent of individual coal seams stem from the custom of considering each coal as a single, indefinitely continuous bed. Most coal names (such as Brookville, Lower Freeport, Sewickley, etc.) actually represent several areally limited individual coal lenses, or multiply-split coal complexes at about the same stratigraphic position within the coal-bearing sequence. Except for the extraordinarily widespread Pittsburgh coal, most coal seams appear to be continuous for at most several thousand square kilometers and usually very much less.

Keeping in mind the fact that individual coal names represent similar stratigraphic position more than actual bed continuity, customary seam nomenclature within each of the coal fields is as shown in figure 16.

OIL AND GAS

Thousands of wells drilled in western Pennsylvania, primarily for Upper Devonian objectives, have penetrated the Carboniferous section. Commercial quantities of both oil and gas have been discovered within the Carboniferous of western Pennsylvania (fig. 17), although this production is at present relatively small in comparison with production from Upper Devonian rocks.

Mississippian system.—The Mississippian System in the subsurface of western Pennsylvania comprises, in upward succession, the Pocono Group, the Greenbrier Group, and the Mauch Chunk Formation. The Pocono Group (used here as a subsurface term) consists of sand and shale and contains several

TABLE 1.—*Pennsylvania coal production (metric tons), 1976*

[Data from Pennsylvania Dept. Environmental Resources, 1977]

Type mine	Bituminous		Anthracite		Combined	
	Tonnage	Number of mines	Tonnage	Number of mines	Tonnage	Number of mines
Deep	40,214,887	159	468,437	109	40,683,324	268
Strip	36,507,906	1,498	2,683,602	119	39,191,508	1,617
Culm and silt bank reprocessing	784,249	16	1,648,660	73	2,432,909	89
Auger	283,428	64	None	None	283,428	64
Total	77,790,470	1,737	4,800,699	301	82,591,169	2,038

hydrocarbon-bearing horizons. These include the Murrysville or Cussewago sand (considered to be the basal Mississippian unit in the subsurface), which is the most important natural-gas-producing horizon within the Carboniferous. The Berea sand is stratigraphically above the Murrysville and is the most important oil-producing horizon within the Carboniferous. The Berea is stratigraphically equivalent to the Corry sandstone but has a different source area. The detailed stratigraphic relationships of the Murrysville, Berea, and Corry sands have been studied by Pepper and others (1954). Other productive sands within the Pocono Group include, in upward succession, the Squaw, the Shenango or Slippery Rock, and the Big Injun or Burgoon sands.

The Loyalhanna, which is commonly a sandy limestone, is a transitional unit between the underlying Big Injun sand and the overlying Greenbrier limestone. The Loyalhanna and Greenbrier are not known to be productive in western Pennsylvania. The Mauch Chunk red shale overlies the Greenbrier Group. The top of the Mississippian System is marked by a major unconformity, and in the subsurface, the Mauch Chunk, Greenbrier limestone, and Loyalhanna are successively truncated to the north by this unconformity.

Pennsylvanian System.—In the subsurface Pennsylvanian System of western Pennsylvania, the Pottsville Group includes the hydrocarbon-bearing Maxton sand, also referred to as the Third Salt or Lower Connoquenessing sand, the Second Salt or Upper Connoquenessing sand, and the First Salt or Homewood sand. The Salt sands produce brine and are also the largest gas producers within the Pennsylvanian System.

The Allegheny Group includes three productive sands: the Clarion or Lower Gas sand; the Kittanning sand, also known as the Middle Gas sand or the First Gas sand; and the Upper Freeport or Upper Gas sand. The top of the Allegheny Group is the Upper Freeport coal. The Upper Freeport coal contains large quantities of methane; in the future, this unit may become an important source of natural gas.

The Conemaugh Group includes several producing sandstone units: the Big Dunkard, also referred to as the Hurryup or the Mahoning sand; the Little Dunkard or Buffalo sand; the Saltsburg sand; and the Murphy or Morgantown sand. The Saltsburg sand is the most important oil-producing unit within the Pennsylvanian System, and the Big and Little Dunkard, which in places merge into one sand referred to as the Dunkard, are together second in importance for the production of oil in the Pennsylvanian System. The Dunkard was the first oil-bearing unit discovered in the Carboniferous; the first producing well was drilled in 1863, just 4 years after the Drake discovery. The Murphy or Morgantown sand is the highest producing sandstone within the Carboniferous.

One other unit must be mentioned within the Pennsylvanian System—the Pittsburgh coal, at the base of the Monongahela Group. Commercial quantities of pipeline-quality gas are being produced from the Pittsburgh coal. Since 1964, the U.S. Bureau of Mines has conducted a comprehensive methane-control research program. Three programs are currently underway in Washington County using methods devised by the U.S. Bureau of Mines to extract methane for commercial purposes from the Pittsburgh coal prior to mining. Gas obtained from coal demethanization could become an important resource in the future.

Nature of traps.—The traps within the sandstone units of the Carboniferous appear to be controlled by lithologic characteristics and minor local structural control. Production is dependent upon porosity, which in turn is dependent upon the original conditions of accumulation of the sediments and their later cementation. Production is in porous and permeable lenticular sandstone which varies greatly in persistence, texture, and thickness.

TABLE 2.—*Recoverable coal resources of Pennsylvania in beds more than 61, 71, and 91 cm thick, by counties and rank, as of January 1, 1970 (millions of metric tons)*

[Data from Edmunds, 1972. Figures are rounded to first two digits (first digit 9 million or less). Numbers will not total exactly because of independent rounding]

COUNTY [1]	Recoverable reserves more than 61 cm thick						Recoverable reserves more than 71 cm thick						Recoverable reserves more than 91 cm thick					
	Total	High-volatile bituminous	Medium-volatile bituminous	Low-volatile bituminous	Semi-anthracite	Anthracite	Total	High-volatile bituminous	Medium-volatile bituminous	Low-volatile bituminous	Semi-anthracite	Anthracite	Total	High-volatile bituminous	Medium-volatile bituminous	Low-volatile bituminous	Semi-anthracite	Anthracite
MAIN BITUMINOUS AND GEORGES CREEK FIELDS																		
Allegheny	770	770	----	----	----	----	620	620	----	----	----	----	240	240	----	----	----	----
Armstrong	1,100	1,100	----	----	----	----	960	960	----	----	----	----	750	750	----	----	----	----
Beaver	620	620	----	----	----	----	320	320	----	----	----	----	180	180	----	----	----	----
Blair	10	----	7	3	----	----	8	----	6	2	----	----	3	----	2	1	----	----
Butler	1,000	1,000	----	----	----	----	780	780	----	----	----	----	330	330	----	----	----	----
Cambria	1,300	----	510	790	----	----	910	----	360	550	----	----	350	----	150	200	----	----
Cameron	17	11	6	----	----	----	11	7	4	----	----	----	0	0	0	----	----	----
Centre	110	----	110	----	----	----	75	----	75	----	----	----	3	----	3	----	----	----
Clarion	570	570	----	----	----	----	410	410	----	----	----	----	73	73	----	----	----	----
Clearfield	910	230	880	----	----	----	650	160	490	----	----	----	82	20	62	----	----	----
Clinton	14	----	14	----	----	----	9	----	9	----	----	----	5	----	5	----	----	----
Elk	130	130	----	----	----	----	100	100	----	----	----	----	42	42	----	----	----	----
Fayette	2,300	1,800	500	----	----	----	1,900	1,500	400	----	----	----	1,000	750	250	----	----	----
Greene	4,100	4,100	----	----	----	----	3,600	3,600	----	----	----	----	2,500	2,500	----	----	----	----
Indiana	2,000	1,500	500	----	----	----	1,500	1,100	400	----	----	----	570	430	140	----	----	----
Jefferson	1,000	1,000	----	----	----	----	800	800	----	----	----	----	240	240	----	----	----	----
Lawrence	150	150	----	----	----	----	140	140	----	----	----	----	70	70	----	----	----	----
McKean	120	120	----	----	----	----	87	87	----	----	----	----	5	5	----	----	----	----
Mercer	100	100	----	----	----	----	74	74	----	----	----	----	19	19	----	----	----	----
Somerset	1,900	----	950	950	----	----	1,500	----	750	750	----	----	610	----	310	300	----	----
Venango	110	110	----	----	----	----	73	73	----	----	----	----	7	7	----	----	----	----
Washington	3,900	3,900	----	----	----	----	3,500	3,500	----	----	----	----	2,400	2,400	----	----	----	----
Westmoreland	2,000	1,500	500	----	----	----	1,800	1,400	400	----	----	----	1,200	960	240	----	----	----
Field totals	24,000	18,000	4,000	1,700	----	----	20,000	16,000	2,900	1,300	----	----	10,000	8,800	1,200	500	----	----
BROAD TOP FIELD																		
Bedford	64	----	----	64	----	----	60	----	----	60	----	----	52	----	----	52	----	----
Fulton	9	----	----	9	----	----	7	----	----	7	----	----	4	----	----	4	----	----
Huntingdon	22	----	----	22	----	----	16	----	----	16	----	----	5	----	----	5	----	----
Field totals	94	----	----	94	----	----	83	----	----	83	----	----	61	----	----	61	----	----
NORTH-CENTRAL FIELDS																		
Bradford	5	----	----	5	----	----	4	----	----	4	----	----	1	----	----	1	----	----
Lycoming	21	----	21	----	----	----	15	----	15	----	----	----	4	----	4	----	----	----
Sullivan	4	----	----	----	4	----	3	----	----	----	3	----	0	----	----	----	0	----
Tioga	17	----	17	----	----	----	12	----	12	----	----	----	4	----	4	----	----	----
Field totals	47	----	38	5	4	----	34	----	27	4	3	----	9	----	8	1	0	----

TABLE 2.—*Recoverable coal resources of Pennsylvania in beds more than 61, 71, and 91 cm thick, by counties and rank, as of January 1, 1970*—Continued *(millions of metric tons)*

[Data from Edmunds, 1972. Figures are rounded to first two digits (first digit 9 million or less). Numbers will not total exactly because of independent rounding]

COUNTY[1]	Recoverable reserves more than 61 cm thick						Recoverable reserves more than 71 cm thick						Recoverable reserves more than 91 cm thick					
	Total	High-volatile bituminous	Medium-volatile bituminous	Low-volatile bituminous	Semi-anthracite	Anthracite	Total	High-volatile bituminous	Medium-volatile bituminous	Low-volatile bituminous	Semi-anthracite	Anthracite	Total	High-volatile bituminous	Medium-volatile bituminous	Low-volatile bituminous	Semi-anthracite	Anthracite
ANTHRACITE FIELDS																		
Carbon	140	----	----	----	----	140	[2]	----	----	----	----	[2]	[3]	----	----	----	----	[3]
Columbia	210	----	----	----	----	210	[2]	----	----	----	----	[2]	[3]	----	----	----	----	[3]
Dauphin	310	----	----	----	150	160	300	----	----	----	150	150	[3]	----	----	----	----	[3]
Lackawanna	150	----	----	----	----	150	[2]	----	----	----	----	[2]	[3]	----	----	----	----	[3]
Lebanon	430	----	----	----	----	430	410	----	----	----	----	410	[3]	----	----	----	----	[3]
Luzerne	740	----	----	----	----	740	[2]	----	----	----	----	[2]	[3]	----	----	----	----	[3]
Northumberland	850	----	----	----	280	560	[2]	----	----	----	----	[2]	[3]	----	----	----	----	[3]
Schuylkill	4,400	----	----	----	400	4,000	[2]	----	----	----	[2]	[2]	[3]	----	----	----	[3]	[3]
Susquehanna	2	----	----	----	----	2	[2]	----	----	----	[2]	[2]	[3]	----	----	----	[3]	[3]
Wayne	3	----	----	----	----	3	[2]	----	----	----	[2]	[2]	[3]	----	----	----	[3]	[3]
Field totals	7,300	----	----	----	830	6,500	[2]	----	----	----	[2]	[2]	[3]	----	----	----	[3]	[3]
TOTALS																		
Pennsylvania total	31,000	18,000	4,000	1,800	830	6,500	20,000	16,000	2,900	1,400	3[4]	[2]	10,000[4]	8,800	1,200	560	0[4]	[3]

[1] Excludes small recoverable reserves from Crawford, Erie, Forest, Potter, Warren, and Wyoming Counties.
[2] Reserves in beds more than 71 cm thick cannot be separately calculated, but in most cases should be 90 percent or more of the tonnages in beds more than 61 cm thick.
[3] Reserves in beds more than 91 cm thick cannot be separately calculated.
[4] Excludes counties of the Anthracite fields.

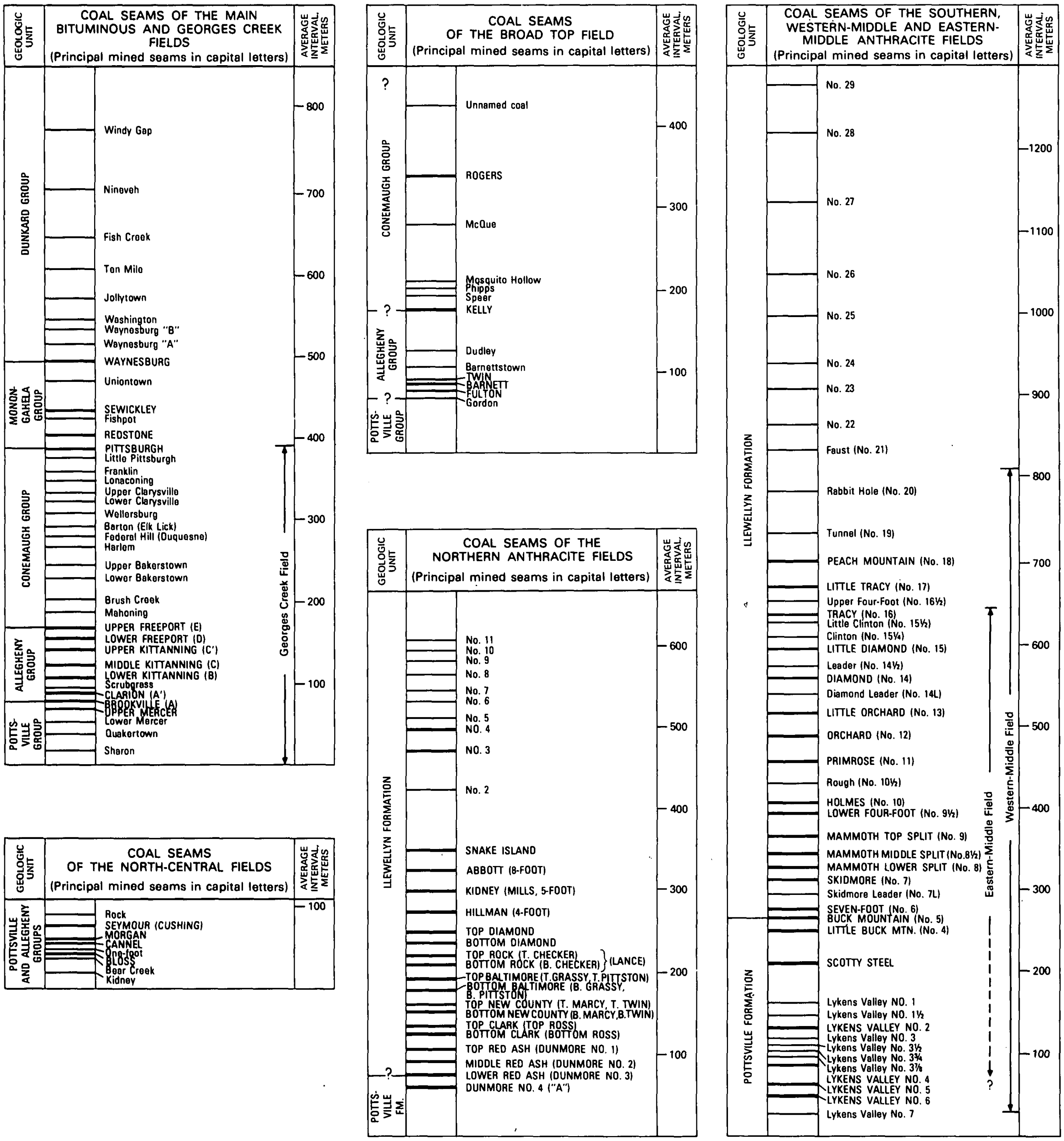

FIGURE 16.—Pennsylvania coal-seam nomenclature.

CLAY AND SHALE

The Pennsylvanian-Mississippian sequence is the source of materials suitable for producing a wide variety of ceramic products including all grades of refractories, most types of brick and tile, lightweight aggregate, and stoneware. The Allegheny Group and uppermost Pottsville Group (Mercer Formation) of western Pennsylvania are the most important sources, yielding most of the refractory-grade clay and lightweight aggregate, as well as much clay and shale suitable for most other types of brick and tile. The Conemaugh and Monongahela Groups, the Rice-

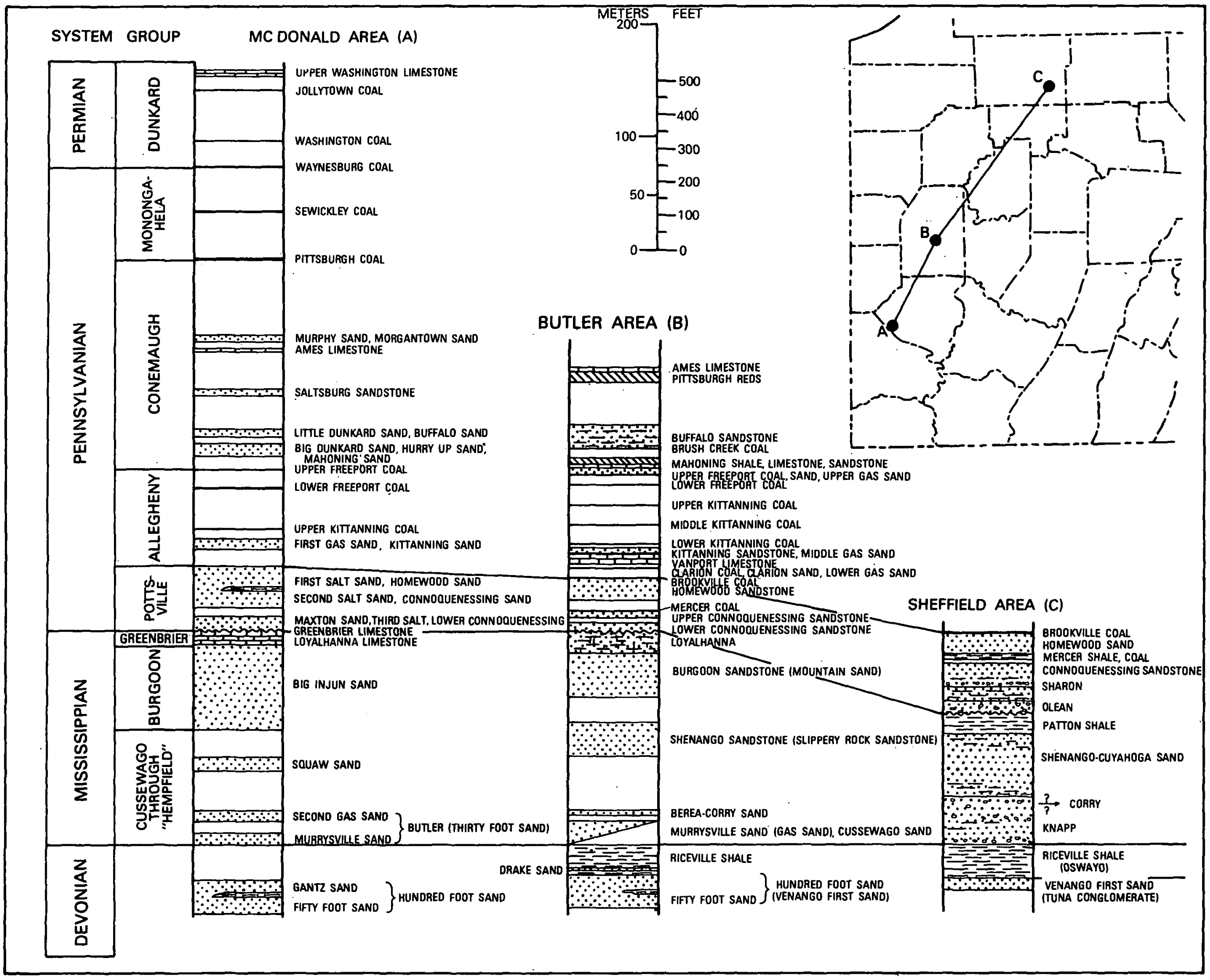

Figure 17.—Generalized columnar section showing stratigraphic position of oil- and gas-bearing sands in Mississippian and Pennsylvanian rocks of western Pennsylvania.

ville-Oswayo to "Hempfield" sequence, and, to a lesser degree, the Mauch Chunk Formation provide raw material for most types of nonrefractory brick and tile. Because of their high content of coarse clastic materials, the Pocono, Burgoon, Huntley Mountain, Rockwell, Spechty Kopf, Pottsville (except Mercer), and Llewellyn have only limited potential for ceramic products.

CARBONIFEROUS ROCKS OF NEW YORK STATE [1]

By Lawrence V. Rickard [2]

The Carboniferous rocks of New York State are in small outliers on the hilltops in the nonglaciated part of southwestern New York, in Allegany, Cattaraugus, and Chautauqua Counties (fig. 1). The rocks consist of thin shale, sandstone, and conglomerate of marine and alluvial origin, in nearly flat-lying beds that have a gentle regional dip in a southerly direction. Rocks of Early Mississippian age are unconformably overlain by those of Early Pennsylvanian age. However, the Pennsylvanian rocks may be found directly upon the latest Devonian strata where Mississippian rocks are absent.

Among the earliest investigations of these beds, the most significant was that conducted in Cattaraugus County (Salamanca and Olean 15-minute quadrangles) by Glenn (1903) and Butts (1903). Subsequently, except for much later work by Caster

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[2] New York State Museum—Geological Survey, Albany, N.Y. 12224.

(1934) and Holland (1958), these rocks have received little attention. The stratigraphic column, given below, is a simple one, there being only three units in New York State.

Pennsylvanian Period
- Pottsvillian Series
  - Sharon Shale
  - Olean Conglomerate

Mississippian Period
- Kinderhookian Series
  - Knapp Formation

The Knapp Formation (Glenn, 1903) consists of two units of conglomerate or sandstone; shale is found above and between these units. Caster (1934) proposed formal names for some of these divisions based on exposures in northern Pennsylvania, but the names have not been used in New York. The Knapp overlies the Oswayo shale and sandstone of the latest Devonian and is unconformably overlain by the Olean conglomerate of Early Pennsylvanian age. The type section of the Knapp Formation is at Knapp Creek Station, near "Olean Rock City" in Cattaraugus County. The formation is about 18 to 32 m thick and is restricted to that county, although several outliers extend westward across the line into Chautauqua County.

The Knapp shale is described as sandy, olive-green, or rusty brown. The conglomerate, often limonitic, contains loosely cemented flat or discoidal quartz pebbles. Both units may be fossilliferous; brachiopods, pelecypods, and some plants have been found. Holland (1958) concluded that the considerable differences in the brachiopod faunas of the Knapp and the underlying Devonian strata confirmed the Mississippian age of the Knapp. The formation is not everywhere present beneath the Olean Conglomerate.

The Olean Conglomerate (Lesley, 1875) varies from a coarse cream-colored quartz sandstone containing few pebbles to a conglomerate almost entirely composed of pebbles. There is much rapid variation, both horizontally and vertically, within the Olean. However, the formation usually consists of a thickly bedded, round or ovoid quartz pebble conglomerate, 15 to 28 m thick. It is strongly cross-bedded, and the pebbles are white, milky, or rose-colored vein quartz, 10 to 90 mm in diameter.

The type section of the Olean is at Rock City, 10 km south of the city of Olean in southern Cattaraugus County, where its enlarged joints form the well-known "Olean Rock City." Elsewhere, the Olean is found in scattered hilltop exposures. Conspicuous ledges of the formation are seen because of its resistance to erosion. The formation appears to be of alluvial origin; plant remains of Pottsvillian age are the only fossils known to be indigenous to the Olean. In places, the conglomerate is at lower altitudes than the Knapp owing to the relief of the unconformity between them.

Virtually nothing is known concerning the occurrence of a thin patch of dark, sandy, ferruginous shales once exposed overlying the Olean Conglomerate near Rock City. These shales have been referred to the Sharon Shale (Rogers, 1858) of Pennsylvania, but their thickness, extent, and fossil content in New York are unknown.

There are no economic resources derived from the Carboniferous rocks of New York State.

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

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ON THE COVER

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

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

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FOREWORD

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

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

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

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

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

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

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

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