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

By THOMAS ARKLE, JR., DENNIS R. BEISSEL, RICHARD E. LARESE, EDWARD B. NUHFER, DOUGLAS G. PATCHEN, RICHARD A. SMOSNA, WILLIAM H. GILLESPIE, RICHARD LUND, C. WARREN NORTON, *and* HERMAN W. PFEFFERKORN

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Prepared in cooperation with the West Virginia Geological and Economic Survey and the Maryland Geological Survey

Historical review and summary of area, stratigraphic, structural, and economic geology of Mississippian, Pennsylvanian, and Lower Permian rocks in West Virginia and adjacent parts of Maryland

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THE MISSISSIPPIAN AND PENNSYLVANIAN (CARBONIFEROUS) SYSTEMS IN THE UNITED STATES— WEST VIRGINIA AND MARYLAND

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ABSTRACT

This review of the upper Paleozoic rocks (Mississippian, Pennsylvanian, and Permian Systems) of West Virginia and Maryland embodies the work of outstanding 19th-century and early 20th-century geologists.

Upper Paleozoic rocks are predominantly composed of fine- to medium-grained clastic materials, which were deposited as a complex delta; exceptions are the organic and chemical deposits interspersed throughout the section. Delineation of facies changes, thickening characteristics and trends of thick units, and distribution of traceable beds such as coal and limestone, suggest structural control of deltaic sedimentation during late Paleozoic time. An irregular surface on Mississippian strata marks a break in sedimentation (unconformity) between Mississippian and Pennsylvanian time, except in areas of continuous sedimentation on or near exposures in southern West Virginia.

Mississippian rocks contain frequent marine horizons. Dally's work on Mississippian invertebrate faunas indicates that Pocono deposition was time-transgressive, ranging from early Kinderhookian through late Osagian in the south, and late Osagean through Meramecian in the north. The Maccrady Formation is Meramecian, although the basal units may be late Osagean. The basal Greenbrier Group is middle Meramecian in the south, correlating with the type area, whereas upper parts of the formations range into the Chesterian. However, the northern Greenbrier is early Chesterian. Mauch Chunk rocks are middle to late Chesterian.

Mississippian vertebrate evidence is sparse. The Pocono and Maccrady have yielded no identifiable vertebrates. Greenbrier rocks contain rare Meramecian vertebrates in the south and somewhat more common Middle and Late Mississippian faunas to the north. Mauch Chunk faunas correlate with the type Chesterian and are similar to Upper Visean rocks in Britain. Appalachian and European Carboniferous floras are very similar, although detailed correlation is hard because of lack of studies.

Invertebrate faunas in Pennsylvanian rocks are relatively uncommon. In the older mining district (southern West Virginia), the Pocahontas and New River Formations contain no useful marine beds. The Kanawha Formation contains several marine faunas of Morrowan, Atokan, and basal Desmoinesian age. Vertebrate evidence is similarly lacking in the older mining district. One basal Kanawha Formation locality yields vertebrates giving a tentative Morrowan age. Allegheny rocks of the younger mining district (northern West Virginia) possess no useful marine beds, although correlative strata in adjacent States are Desmoinesian. Lower Conemaugh marine zones are Missourian through lower Virgilian in age. Upper Conemaugh, Monongahela, and Dunkard beds are barren of marine fossils.

Conemaugh and early Monongahela vertebrates in the younger mining district show Virgilian affinities. Sediments above the Benwood limestone contain vertebrates corresponding to Wolfcampian faunas. The upper part of the Greene Formation above the Burton sandstone has a possible Leonardian correlation. Pennsylvanian paleobotany needs more study, but a basic zonation is being worked out and correlated with the European sequence.

INTRODUCTION

Upper Paleozoic rocks underlie 81 percent of western and southern West Virginia and much of Garrett County, smaller areas of Allegany County, and a few hilltops of Washington County in Maryland. This paper reviews the early geologic work, physiography, structure, and mineral resources, and focuses upon the lithostratigraphy and biostratigraphy.

Figure 1 shows the historical development, to the present, of West Virginia/Maryland late Paleozoic nomenclature. It also shows the approximate relationships of rock divisions to (1) U.S. midcontinent series time-rock units, and (2) the European stages (Moore and others, 1944, chart 6; Weller and others, 1948, chart 5; Dunbar and others, 1960, chart 7; McKee and Crosby, 1975, p. 2).

The Mississippian and Pennsylvanian sections in the United States are approximate equivalents of,

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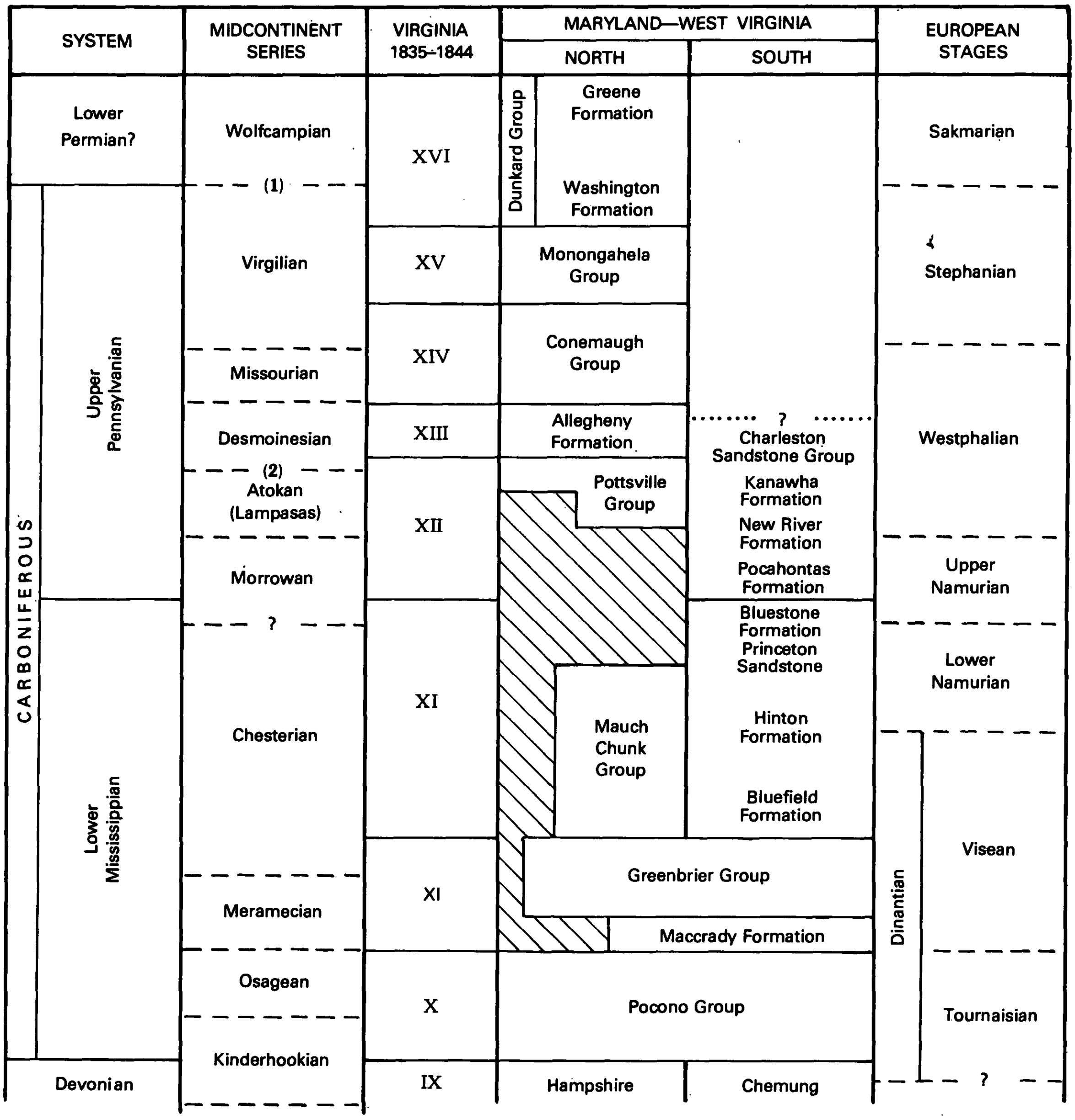

(1) Position of Washington coal. (2) Position of Coalburg or Stockton coals.

FIGURE 1.—Late Paleozoic classification.

respectively, the lower and upper Carboniferous of Europe. The term "Permo-Carboniferous" (Wilmarth, 1938, p. 1640) was commonly used in early geologic reports in the United States, following the practice of many European workers. The U.S. Geological Survey included the Permian Series as the upper epoch of the Carboniferous until 1941 (Dunbar and others, 1960, p. 1767). The Dunkard Group, essentially of Permian age, is included in this discussion, because sedimentation continued without interruption from the Monongahela Group of Pennsylvanian time into the Dunkard Group. A long controversy continues over the assignment of the Dunkard Group to the Permian System (Fontaine and White, 1880, p. 105–120; Dunbar and others, 1960, p. 1789, 1790; Barlow, 1975, p. vii–xviii).

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 West Virginia Geological and Economic Survey, with the exceptions of the term "Charleston Sandstone Group" (fig. 1) and Lower No. 5 Block, Upper No. 5 Block, and No. 6 Block coals (R. S. Reppert, oral commun., 1977) (fig. 10).

ACKNOWLEDGMENTS

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Biostratigraphic material was prepared as follows: Mississippian, Pennsylvanian, and Permian plants, by William H. Gillespie, West Virginia University, Morgantown, W. Va., and Herman W. Pfefferkorn, University of Pennsylvania, Philadelphia, Pa.; Mississippian, Pennsylvanian, and Permian vertebrates, by Richard Lund, Adelphi University, Garden City, Long Island, N.Y.; Pennsylvanian invertebrates, by C. Warren Norton, and Mississippian invertebrates, by Richard A. Smosna, both of the West Virginia Geological and Economic Survey, Morgantown.

The remaining sections of the paper were prepared by members of the staff of the West Virginia Geological and Economic Survey: Introduction, early geologic work, physiography, structure, coal, and lithostratigraphy of Pennsylvanian and Permian Systems, by Thomas Arkle, Jr.; ground water, by Dennis R. Beissel; construction and industrial minerals and iron ore, by Edward B. Nuhfer and Richard E. Larese; oil and natural gas, by Douglas G. Patchen; and lithostratigraphy of Mississippian System, by Richard A. Smosna.

EARLY GEOLOGIC WORK

A colonial military road crossed Maryland and Pennsylvania to Fort Duquesne (Pittsburgh) in the mid-18th century. This road was extended to Wheeling in what was then western Virginia and became the National Road in 1818, parts of which are now U.S. Route 40. Improvements to this road and the completion in 1852 of the Baltimore and Ohio Railroad across Maryland and northwestern Virginia (between Baltimore and Wheeling) opened the area for geologic study and subsequent mineral developments during the first half of the 19th century.

The major rock divisions of late Paleozoic age in western Viriginia (much of which became West Virginia on June 20, 1863) and Maryland (fig. 1) were first studied and described between 1835 and 1844 by W. B. Rogers (1884), State Geologist of Virginia, and by his brother H. D. Rogers (1838, 1840, 1844, 1858), State Geologist of Pennsylvania.

The Rogers brothers (Pennsylvania's First Survey) and the staff of the Second Pennsylvania Geological Survey in 1875, under J. P. Lesley (1876), contributed greatly to geologic knowledge of Maryland, the Virginias, Pennsylvania, and Ohio.

The first Maryland Geological Survey was organized in 1833 under J. T. Ducatel, State Geologist, and J. B. Alexander, State Topographic Engineer; the third and present Maryland Survey was organized on March 11, 1896, under William B. Clark (1897, 1905). The West Virginia Geological Survey was organized on February 20, 1897, under Israel C. White (1891, 1903, 1908), formerly of the Pennsylvania and U.S. Geological Surveys.

A growing coal industry focused on commercial coals during the first quarter of the 20th century. Correlation problems, particularly in Middle Pennsylvanian strata, were posed by bed configuration and lithofacies changes between the strata deposited on the northwestern West Virginia/Maryland craton and the southern West Virginia basin.

The paleobotanical work of White (1900a, b; 1913), showed that northern West Virginia's Allegheny Formation coal was younger than that of southern West Virginia's Kanawha Formation. Campbell (1903) resolved the mapper's dilemma by showing a facies change involving the stratigraphic equivalents of: (1) the upper Pottsville (Homewood sandstone), Allegheny, and lower Conemaugh strata of northern West Virginia; and, (2) the Charleston sandstone (Campbell, 1901, p. 5) along the Elk River near Charleston (fig. 1).

Geologic maps and reports on the upper Paleozoic rocks of West Virginia were completed between 1906 and 1939 by G. P. Grimsley, Ray V. Hennen, C. E. Krebs, D. B. Reger, J. L. Tilton, P. H. Price, and L. M. Morris, assisted by W. A. Price, Rietz C.

Tucker, W. F. Prouty, D. D. Teets, Jr., Robert M. Gawthrop, and E. T. Heck of the West Virginia Geological Survey, and David G. White and George H. Girty of the U.S. Geological Survey.

Maps and reports on upper Paleozoic geology in Maryland's Allegany, Garrett, and Washington Counties were completed between 1900 and 1951 by Cleveland Abbe, Jr., G. C. Martin, C. C. O'Hara, W. B. Clark, R. B. Clark, R. B. Rowe, Heinrich Ries, and Ernest Cloos, of the Maryland Geological Survey, which by the 1950's had become the Maryland Department of Geology, Mines, and Water Resources. The stratigraphy of Maryland's coal measures was revised in the second coal report (Swartz and Baker, 1922). During World War II, exploration for coal and refractory clay by the U.S. Bureau of Mines and the U.S. Geological Survey culminated in the remapping of the Pennsylvanian of Maryland. This remapping was done in the early 1950's by Karl Waage of the U.S. Geological Survey and T. M. Amsden of the then Maryland Department of Geology, Mines, and Water Resources. (fig. 2).

PHYSIOGRAPHY

The upper Paleozoic strata of West Virginia and Maryland form part of the Appalachian Plateaus province (fig. 3) and limited synclinal-mountain areas of the Valley and Ridge province farther east. The Appalachian Plateaus province extends from west of the Ohio River eastward across the Allegheny Mountain section of the plateau, to the Allegheny Front. The Allegheny Front is underlain by resistant Pottsville sandstone. The steep slope to the east, leading down to the Valley and Ridge province,

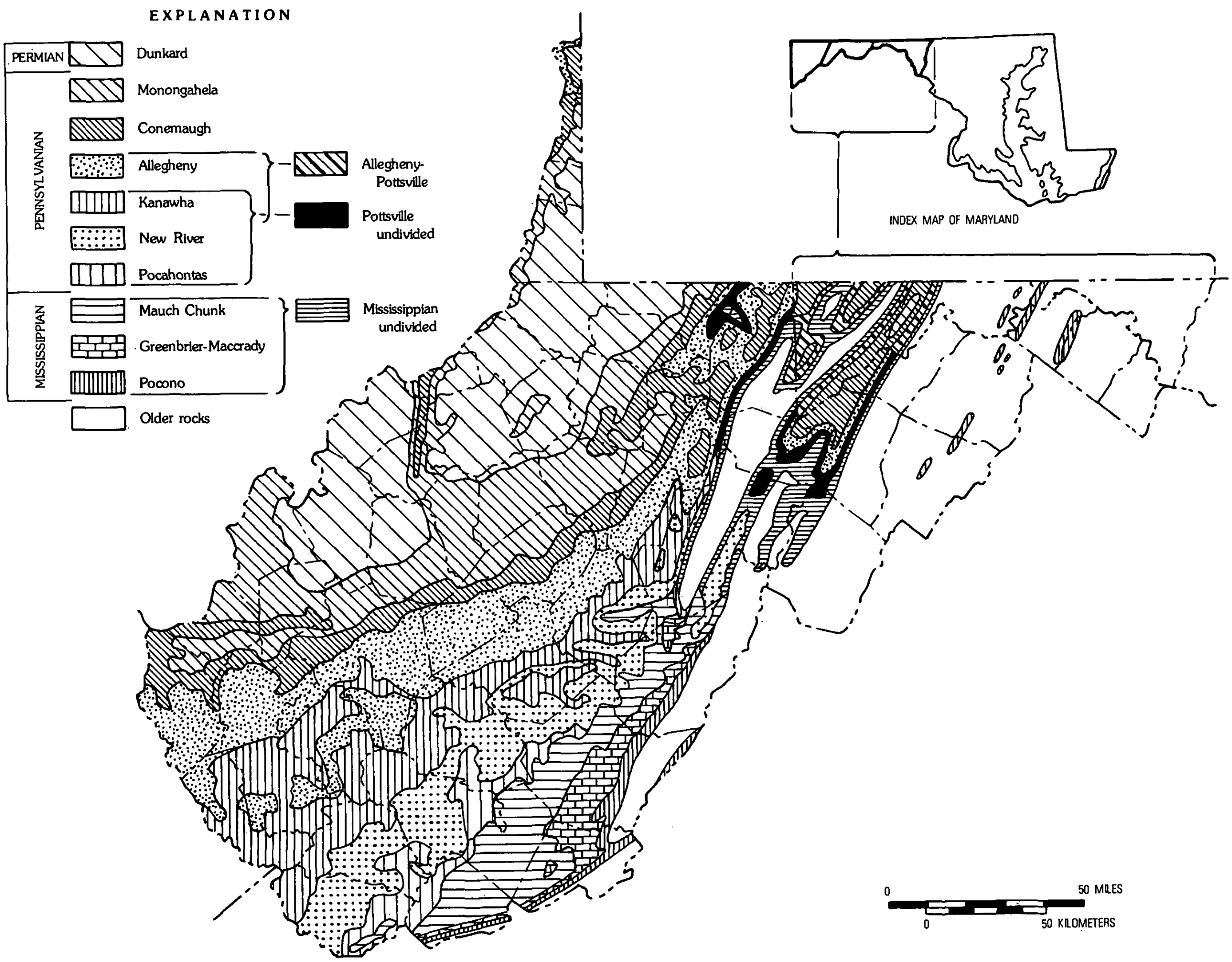

FIGURE 2.—Geologic map of the late Paleozoic of West Virginia and Maryland.

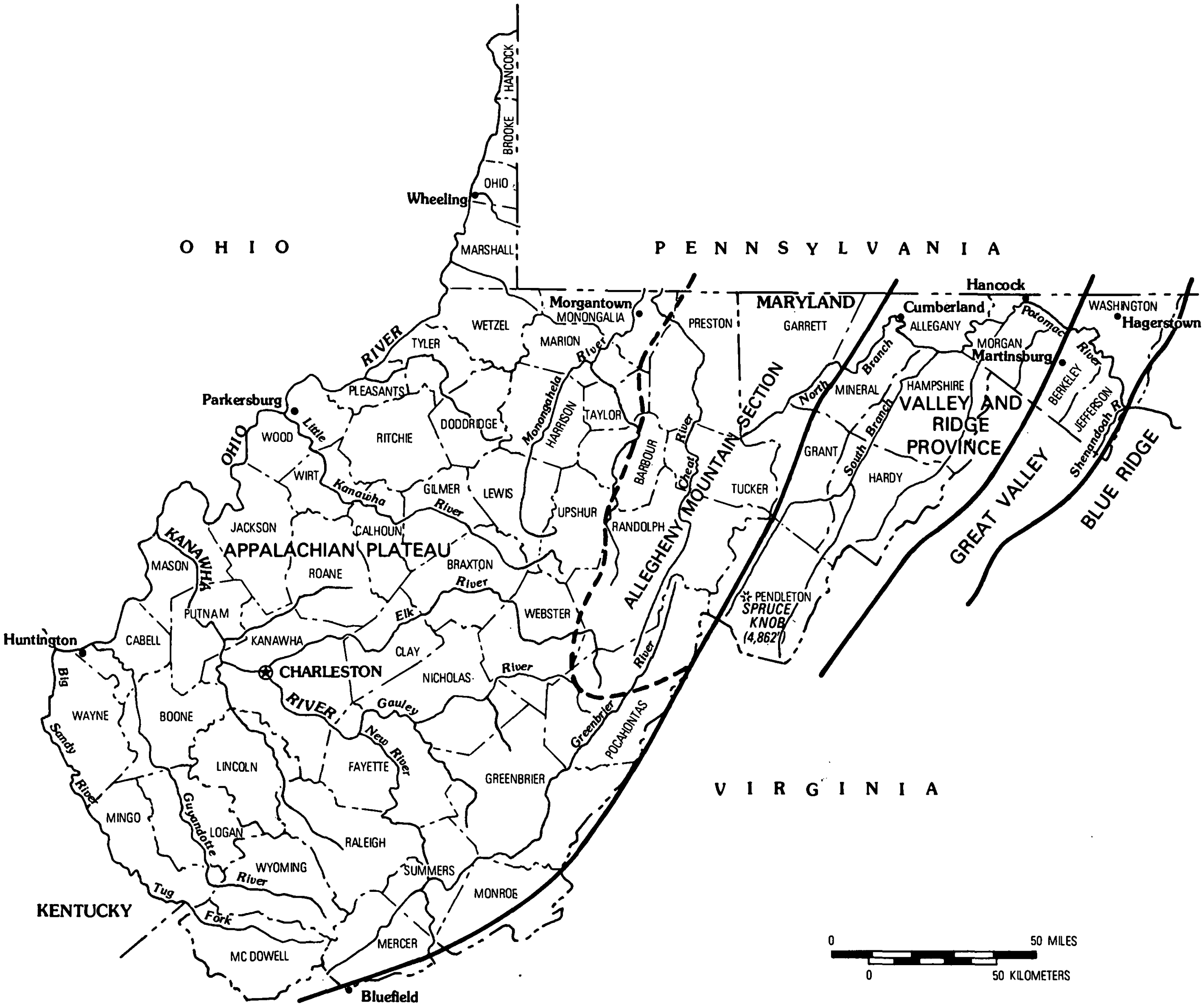

FIGURE 3.—Physiographic map of West Virginia and adjacent Maryland.

is on less resistant Mississippian and older strata. The Appalachian Plateaus province is deeply dissected, hilly to mountainous country, and the outliers are linear mountainous ridges of sandstone and shale containing a few irregular coal beds (figs. 2–4).

The water of the plateau and southeastern Lower Mississippian outliers drains westward to the Ohio River. As shown in figure 3, the north-flowing Monongahela drainage, the south-flowing Greenbrier River, and the west-flowing Elk and Little Kanawha Rivers all begin in the high country of Randolph and Upshur Counties near Spruce Knob, Pendleton County, the highest point in West Virginia (1,482 m or 4,862 ft) and the environs of the Catskill-Pocono stratigraphic anomaly (Flowers, 1956, p. 8, 10–14; fig. 4). Waters of eastern Tucker, Grant, and Mineral Counties, West Virginia, the eastern slope of the Allegheny Front, most of western Maryland, and the northern lower Mississippian outliers flow into the Potomac River, thence east to the Chesapeake Bay and the Atlantic Ocean.

Only two rivers entirely cross West Virginia: the Ohio crosses the State from north to south, and the New/Kanawha Rivers, as a system, cross east to west. The Ohio River's glaciofluvial sand-and-gravel deposits are dominated by rock debris from hard sandstone and quartzite that emanated from ablat-

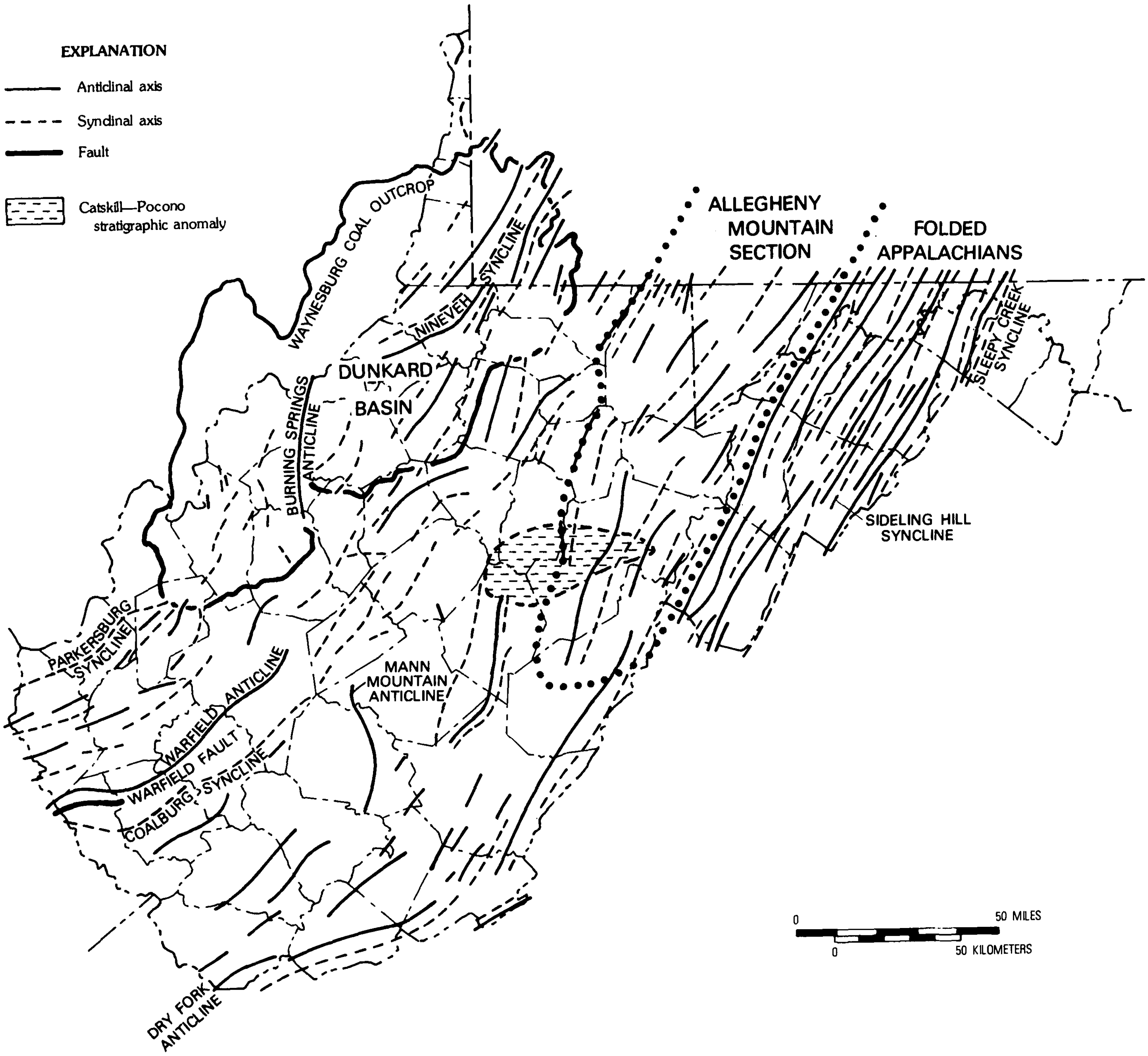

FIGURE 4.—Structural map of the late Paleozoic of West Virginia and Maryland.

ing Pleistocene glaciers north of West Virginia. The New/Kanawha River system begins near Blowing Rock in North Carolina's Blue Ridge Mountains and flows across the Valley and Ridge province, and the Appalachian Plateaus province to Point Pleasant on the Ohio River. Some granitic and metamorphic rocks are present in the bedload deposits of the New/Kanawha Rivers. The bedload sand-and-gravel deposits of all other streams of West Virginia are largely of sandstone, the rock most resistant to physical and chemical disintegration, and other sedimentary rock types indigenous to the Valley and Ridge and Appalachian Plateaus provinces.

STRUCTURE

The upper Paleozoic strata of West Virginia and Maryland are exposed on the eastern side of a synclinal belt extending north-northeast from the subsurface in Alabama to near the Great Lakes in Ohio and New York, a distance of 1,448 km (900 mi) (fig. 4). These strata are infolded between the Appalachian tectonic belt on the east and the more stable Indiana-Ohio upland and the Lexington (Kentucky) and Jessamine (Tennessee) domes on the west.

Early work depicted the surface structures of upper Paleozoic strata as reflections of episodic basement deformation. The deformation intensity declined progressively from the crystalline Appalachians (Piedmont and Blue Ridge provinces) on the east to the basement of the sedimentary Appalachians (Valley and Ridge and Appalachian Plateaus provinces) on the west. Since World War II, however, deep drilling for natural gas on anticlinal structures of the sedimentary Appalachians has found many thrust faults. A restudy of the structures, based on drilling, geophysical logging, and surface geological investigations, suggests this alternative view of Appalachian tectonics: A dêcollement zone (perhaps in Silurian evaporites) and associated thrust faults extending upward into Middle Devonian strata, plus folding, are suggested as the mechanisms for the formation of surface structures in the Valley and Ridge and subsurface structures in the Appalachian Plateaus. Structural manifestations in Cambrian and Precambrian strata are believed coincidental to this later tectonic activity in the Valley and Ridge province and subsurface of the Appalachian Plateaus province (Rodgers, 1972).

Delineation of facies changes, thickening characteristics and trends of thick units, and distribution of traceable beds such as coal and limestone, suggest later structural control of deltaic sedimentation during late Paleozoic time (Arkle, 1974). Compressional forces formed the surface structure of the Appalachians from at least Mississippian time through the rest of Paleozoic deposition, after the earlier period of extensional tectonics. The entire rock section was further deformed at the end of Paleozoic deposition (Rodgers, 1972, p. 4).

Two surface-structural trends, running east-northeast and north-northeast, are evident in West Virginia (note arrows in fig. 8, and relate these to fig. 4). These trends conform to the structural salients of the Appalachian Mountains. Southern West Virginia's upper Paleozoic strata are shown in a northeast-trending, northwest-dipping broad monoclinal structure (fig. 4). Strata inclination is moderate, reaching 48 m/km (250 ft/mi) on the Warfield anticline, the dominant structure. This dip increases to 57 m/km (300 ft/mile) on the Dry Fork anticline, bringing Upper Mississipian strata to the surface and exposing basal Pennsylvanian beds just to the southeast. Farther southeast, in southeastern Mercer and Monroe Counties (see fig. 3 for county location), deformation intensity of the thick, less resistant Mississippian strata increases progressively between the higher Pennsylvanian escarpment and the Valley and Ridge province, where middle and lower Mississippian (and older) strata are vertical or slightly overturned (figs. 2–4).

En echelon structures, trending north-northeast in the Allegheny Mountain section (figs. 3 and 4) bring resistant Pottsville sandstone to the surface, forming mountainous areas. More hospitable country is formed on the less resistant Mississippian and Devonian strata in breached anticlines and on the younger Pennsylvanian coal-bearing strata in adjacent synclines. Anticlines are slightly asymmetric to the west, and maximum dips are 20°. The anticlines plunge south-southwest over the Catskill-Pocono stratigraphic anomaly and lose identity in southern West Virginia monoclinal structure.

The Nineveh syncline is the axis of the Dunkard basin, a north-northeast-trending synclinorium extending from Huntington, W. Va., to Pittsburgh, Pa. The basin configuration is best delineated by Pittsburgh coal exposures (fig. 4). Normal to the Nineveh syncline, the Pittsburgh coal is 518 m (1,700 ft) above sea level on Scotch Hill, Preston County, and 320 m (1,050 ft) at the head of the Monongahela River in Marion County, both in west Virginia; it is 378 m (1,240 ft) at its western exposure in Belmont County, Ohio. The Pittsburgh coal is slightly above sea level along the Nineveh axis in West Virginia. West of the Allegheny Mountain section, strata in the synclinorium dip 38 m/km (200 ft/mi), decreasing to less than 4 m/km (20 ft/mi) on the Ohio River.

The anomalous Burning Springs anticline lies athwart the Dunkard basin axis. This anticline is complex, steeply dipping, north-trending and plunging, and is surrounded by nearly flat-lying strata. Surface dips range from as much as 55° on a narrow flat crest on the east flank, to 70° on the west flank. Here, as on many other anticlines in the Appalachian Plateaus province, deep drilling has disclosed thrust faults extending into the Devonian. Projection of the relatively simple Appalachian Plateaus surface structures into the subsurface is not valid because they may not be maintained at depth (Woodward and others, 1959, p. 164).

MINERAL RESOURCES

Mineral resources from upper Paleozoic rocks (fig. 5) are economically important to West Virginia and Maryland. Coal accounted for 94 percent of West Virginia's mineral resources, which were

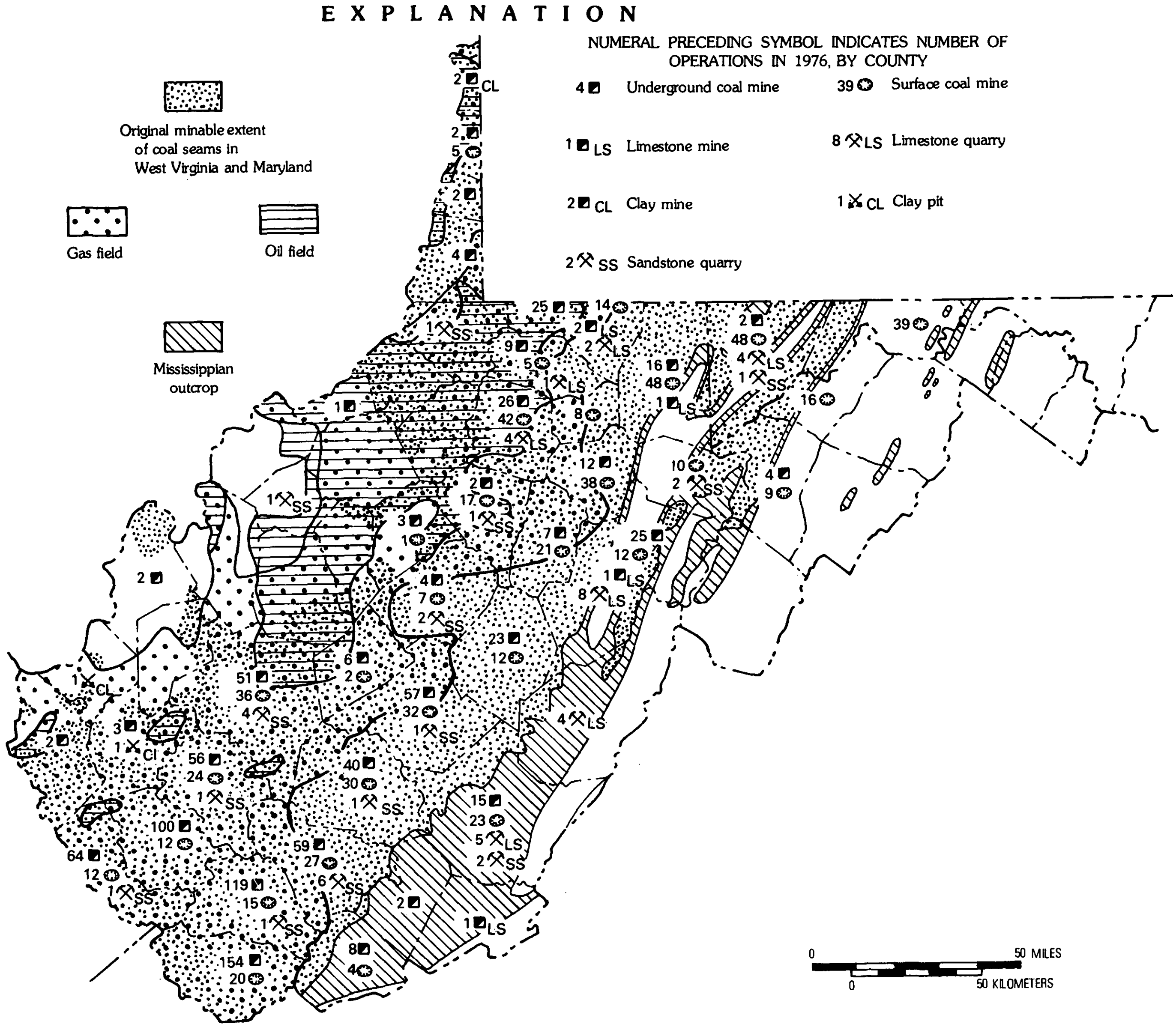

FIGURE 5.—Late Paleozoic mineral resources of West Virginia and Maryland.

valued at $3.5 billion (at the source) in 1976; it accounted for 28 percent of Maryland's mineral resources, valued at $172.9 million in 1974. Upper Paleozoic strata also provide the following materials in West Virginia and Maryland: all the refractory clay; all the concrete sand from crushed sandstone; most of the oil, clay, shale, and crushed sandstone; appreciable natural gas; appreciable limestone for aggregate and cement manufacture; and some industrial limestone.

COAL

During the mid-1700's, explorers and surveyors noted the existence of coal in West Virginia and Maryland. In 1811, coal fired the first steamboat on the Ohio River. In 1840, W. B. Rogers (1884) reported coal production of 271,157 t (metric tons) (298,894 short tons) in West Virginia; about 70 percent of this coal was used by the salt industry on the Kanawha River above Charleston.

In Maryland, two coal mines operated as early as 1782 and 1804. Coal was carried east to Cumberland, Md., over the National Road as early as 1820. Access to the northern coal fields was provided by the Chesapeake and Ohio Canal (completed in 1850) and the Baltimore and Ohio Railroad (completed in 1843), both connecting the eastern seaboard to Cumberland.

West Virginia coal production increased slowly until the completion of the rail network in the late 1800s. Original coal resources, measured to 30.5 cm (12 in.) thick in the western 69 percent of the State, were estimated at 105.9 billion t (116.7 short tons). Production expanded rapidly to 132.5 million t (146.1 million short tons) in 1927. Only during World War II and the postwar years to 1947 did production exceed 136.1 million t (150 million short tons). Production remained high through the recent 1965–67 peak, and fell irregularly to a 92.3-million-t (101.7 million short tons) low in 1974. Coal production in 1976 was 98.1 million t (108.1 million short tons) from 903 underground and 504 surface or "outside" mines (West Virginia Dept. Mines, 1976, p. 15) ; surface mining accounts for 19 percent annually.

More than 70 percent of West Virginia's annual coal production comes from low- to high-volatile, generally low-sulfur (<1 percent) seams at multilevels in southern West Virginia. The remainder is produced from high-volatile, high-sulfur (>1 percent) coal of northern West Virginia, principally the thick, uniform Pittsburgh coal. Correlative coals grade into low- to medium-volatile (and locally low-sulfur) coal in the Allegheny Mountain section (fig. 4) of West Virginia and Maryland. Much of Maryland's early production was from the Pittsburgh coal in Allegany County, but when this coal was depleted early in the 20th century, mining shifted to the less uniform and thinner Allegheny and Conemaugh coals.

About a third of the coal production of West Virginia is used to generate electricity annually, more than half is used domestically or exported for metallurgical purposes, and the remainder supplies industrial and retail markets. Mining employment reached 121,280 in 1923. After machines were introduced, employment declined to 41,593 in 1968, and stood at 59,802 in 1976 (West Virginia Dept. Mines, 1976, p. 13–14).

West Virginia coal reserves are estimated at 33.1 billion t (36.5 billion short tons) from seams >71.1 cm (28 in.) thick. Appreciable reserves <71.1 cm (28 in.) thick are available. About 1.9 billion t (2.1 billion short tons) of reserves is recoverable by surface mining. Some 33.4 percent of reserves is low-sulfur (<1 percent) coal (U.S. Bur. Mines, 1971, p. 118; 1974, p. 275).

Maryland's coal production increased from 1,548 t (1,706 short tons) in 1842 to a 5.0-million-t (5.5 million short tons) peak in 1907. Subsequently, production averaged about 4.1 million t (4.5 million short tons) per year until 1918, and thereafter declined irregularly to a 453,600-t (500,000 short tons) low in 1954. In recent years, coal production for steam generation has increased slowly to a 2.4-million-t (2.7 million short tons) high in 1976. Surface-mining methods, introduced during World War II, now account for 94 percent of Maryland's coal production.

Total recoverable reserves in Maryland are estimated at 775.6 million t (854.9 million short tons) for seams more than 68.6 cm (27 in.) thick. About 90.7 million t (100 million short tons) is recoverable by surface-mining methods; the remainder is recoverable only by underground mining. Additional coal reserves exist in seams thinner than 68.6 cm (27 in.) (Weaver and others, 1976, p. 1–3).

OIL AND NATURAL GAS

West Virginia's oil and gas industry began with oil production from the Rathbone Well (Wirt County) in 1859. The State ranked second or third in crude oil production from then until 1900, the peak year. Production and the State's rank have both decreased steadily during this century. Annual oil production is now only 12 percent of 1900's, and annual gas production is now about 52 percent of that produced during the peak gas year, 1916.

During the early years of the industry (the last half of the 19th century), shallow Pennsylvanian sandstone (Pottsville, Allegheny, Conemaugh, and Monongahela strata) along the Burning Springs anticline and Ohio River was drilled for oil and associated natural gas. Deeper drilling penetrated important oil and natural-gas reservoirs in Mississippian sandstone and in thin basal Greenbrier sandy dolomite in western West Virginia. More recently, natural-gas reservoirs have been developed in Mississippian sandstones in southern West Virginia (fig. 5). Driller's names have been given to 11 Mississippian and 10 Pennsylvanian producing sands between the Berea sand (base of Pocono Group) and the Minshall sand (Monongahela Group).

West Virginia has 357 fields in 53 counties; Maryland has 1 field. In West Virginia, oil and natural gas are produced from upper Paleozoic reservoirs in 43 of the 53 counties; in Maryland, no county produces oil or gas from upper Paleozoic rocks.

At the end of 1976, West Virginia's original oil in place was estimated at 351,966 thousand t (2,625,-316 thousand barrels), 10.7 percent in Pennsylvanian reservoirs and 58.5 percent in Mississippian. An estimated 73,089 thousand t (545,173 thousand bbls) was assumed to be recoverable, 6.6 percent in

Pennsylvanian and 55.3 percent in Mississippian reservoirs.

Currently, Pocono and Greenbrier reservoirs are the most common Mississippian targets in the State for development and in several southern counties for exploration. The Mauch Chunk sands are also productive in this southern area. In Pennsylvanian strata, only basal sands are being developed at present.

CONSTRUCTION AND INDUSTRIAL MINERALS

Limestone.—Commercial limestone production (fig. 5) indicates the economic importance of the Mississippian Greenbrier Group. The Greenbrier, a group of marine limestones, has exceptional thickness, persistent continuity, generally acceptable purity, and extensive areas of surface exposure. Most Greenbrier limestone is used for road aggregate, cement, and agricultural lime. High-purity limestone from the southern counties is also used as rock dust in coal mines.

Lateral and vertical variations in purity are documented in the Greenbrier Group. Textural and mineralogical variations along the northeast-trending outcrop belt from Tucker County to Monroe County W. Va., have been described by Leonard (1968). The entire limestone sequence of the Greenbrier is usable, but the highest purity limestone is found in the Union Formation. The "white oolite member" of the upper Union (Leonard, 1968, p. 101) persists through Monroe County and much of Greenbrier County, where it is extensively quarried. As the oolitic beds diminish in size and continuity to the northeast, limestone purity generally decreases. Westward, beneath the plateau, insoluble residues generally increase as the Greenbrier grades toward the sandier facies found in the subsurface of western West Virginia. Four quarries operate in the basal sandy Greenbrier (Loyalhanna) in Garrett County, Md.

Present mining operations are restricted to outcrop areas and include both open-pit and underground mines (Larese and others, 1977). The underground mines enter surface exposures and follow only the gentle dips of the strata. Deep shaft mining in western West Virginia has been discussed (Kusler and Corre, 1968) but has not yet been undertaken.

Some thin Pennsylvanian limestone beds of minor economic importance are utilized locally. These beds were described by McCue, Lucke, and Woodward (1939); they were further discussed and were classified according to their usability, by the West Virginia University Coal Research Bureau (1965). Most of this limestone is nonmarine; a lacustrine origin has been attributed to some beds. All beds have persistently high dolomite and (or) insoluble-residue content and are not potential sources of high-calcium limestone. Of these beds, the Benwood and Redstone limestones of the Monongahela Group are the most important commercial sources. Benwood exposures occur in Ohio, Brooke, Tyler, Doddridge, and Harrison Counties; minable thicknesses of the Redstone occur in Monongalia, Harrison, Marion, and Upshur Counties. Present extraction yields local road aggregate and minor amounts of agricultural lime.

Sandstone.—Upper Paleozoic sandstone is currently extracted in 23 quarries in 13 counties (fig. 5) and is used as road-base aggregate, concrete sand, and, to a lesser extent, dimension stone.

High-silica (98 percent) sandstone is mostly restricted to the Pottsville Group (Lower Pennsylvanian), Mauch Chunk Group (Upper Mississippian), and Pocono Group (Lower Mississippian) (Arkle and Hunter, 1957). In northern West Virginia, the Connoquenessing and Homewood Sandstones (Pottsville Group) have been quarried for glass sand. In the southern part of the State, high-silica material at the horizons of the Nuttall, Raleigh, and Pineville sandstones (New River Formation, Pottsville Group) underlies small areas, which are suitably located for mining (Arkle and Hunter, 1957).

Sandstones of the Mauch Chunk and Pocono Groups are impure, commonly containing appreciable argillaceous material; consequently, many do not qualify for high-silica applications. However, two sandstones within the Mauch Chunk Group, the Stony Gap and Droop, are relatively pure and may have potential as special-purpose sands. An additional pure quartz-cemented conglomeratic member of the Pocono Group has been quarried for construction aggregate in Preston County and adjacent areas of Maryland.

The youngest Paleozoic sandstones in West Virginia—the Conemaugh-Monongahela Group in the Pennsylvanian and the Dunkard Group in the Permian—are generally too impure to be high-silica sandstone sources. These units are locally quarried for road-base aggregate and historically have been used for dimension sandstone and abrasive stone (grindstone, pulpstone) (Eggleston, 1975).

Clay and shale.—West Virginia's clay and shale industry is relatively small. Four mines produce clay and shale for manufacturing common brick, fire brick, block, and clay stemming.

Only clay and shale of the Pennsylvanian Allegheny Formation and Conemaugh Group are currently being used. Two Allegheny clays, the Lower Kittanning and Clarion, have excellent fire-clay qualities and are presently being extracted by underground methods in Hancock County (fig. 5). These clays directly underlie the Lower Kittanning coal, and range from 2.1 to 6.7 m (7 to 22 ft) in thickness in the northern panhandle. Reserves have been estimated at 1 billion tons under less than 500 feet overburden (Cross and Schemel, 1956). Allegheny plastic and flint clays are mined for production of refractory fire brick and ground-and-calcined clay in adjacent parts of Maryland. Conemaugh shale is extracted from two quarries in Cabell and Lincoln Counties for manufacture of common brick, tile, and clay stemming.

Recent work by Lessing and Thomson (1973) has shown that many late Paleozoic clays and shales have potential for the manufacture of face brick, structural tile, lightweight aggregate, and sewer pipe.

Salt.—Natural brines from upper Paleozoic strata have been used extensively in West Virginia, although the State's brine fields are presently inactive. Major sources were the "Salt Sands" in the Pennsylvanian Pottsville Group and the "Big Injun Sand" of the Mississippian Pocono Group. A compilation of geological information, production sites, chemical analyses, and economic utilization of these brines has been provided by Price and others (1937).

IRON ORE

Although there is no present iron mining in West Virginia, an active history of production from Pennsylvanian rocks was noted by Eggleston (1975, p. 25) and Grimsley (1909, p. 106–107). The latter reference also gives the location, analyses, and nature of the ore in various counties. Iron deposits from Pennsylvanian strata consist of impure sideritic-limonitic nodular beds which are discontinuous and sporadically distributed through the coal measures in a broad belt from Preston and Monongalia Counties through Kanawha and Wayne Counties. These occurrences will probably not be economically important in the foreseeable future. The sites, together with the abandoned remnants of iron furnaces and the implements made there, are mainly of historical interest.

GROUND WATER

Three factors affect water quality from upper Paleozoic strata: (1) Mine drainage from Pennsylvanian strata pollutes water, principally in the northern part of the State, (2) in the oil and gas fields (fig. 5), fresh water is degraded by upward migration of brine, and (3) variable ground-water quality conditions, both within and between aquifers, are caused by local geologic, hydrologic, and cultural phenomena.

MISSISSIPPIAN SYSTEM

Ground-water availability is highly variable in the Mississippian outcrop belt in West Virginia. Clark and others (1976) found well yields in southeastern West Virginia to be governed primarily by well depth, topography, geologic structure, and stratigraphy. Yields were generally higher in deep wells, valley wells, and wells near axes. Valley wells in the Mauch Chunk Group had a higher median specific capacity than wells in any other Mississippian unit.

Ground-water occurrence in the karst region, underlain by Greenbrier limestone in southeastern West Virginia, is controlled by interconnection of solution cavities and channels along fracture systems in carbonate strata. Wells in the Maccrady Formation and Pocono Group yield moderate water, but hillside and hilltop wells in the Maccrady may not yield enough for domestic use (Clark and others, 1976).

In northeastern West Virginia, wells penetrating the Greenbrier and Pocono Groups have yields adequate for domestic use. Few wells tap Mississippian-age rocks outside the outcrop belt in eastern West Virginia and western Maryland; consequently, yield data are scarce. In the subsurface of western West Virginia, Mississippian-age rocks are usually below the freshwater/saltwater interface.

PENNSYLVANIAN AND PERMIAN SYSTEMS

Southern West Virginia.—Ground-water data for Pennsylvanian strata in southern West Virginia are scarce. A water-resources study of this area's Guyandotte River basin is in progress.

Pottsville Group sandstones are the most extensive aquifers in southern West Virginia. Doll and others (1960) found that Pottsville sandstone in Kanawha County yields more water than does shale of the same group. Well yields ranged from 1 to 522 gpm, averaging 118 gpm. The freshwater/saltwater interface is 90–150 m (300–500 ft) deep. Wilmoth (1967) reported 88,000 gpd/ft transmissivity from an aquifer test in the Pottsville Group in Raleigh County. To the southeast in the New River basin, Clark and others (1976) found Pottsville wells to have a median specific capacity of 0.23 gpm/ft. They suggested that valley wells in the Pottsville would yield sufficient water for small municipal and industrial supplies.

Sandstones overyling the Pottsville are also major aquifers in southern West Virginia. Wells in these sandstones produce primarily from fractures. In Kanawha County, the average well yield was 125 gpm, the deepest freshwater well being at 93 m (306 ft) (Doll and others, 1960). A 13,000-gpd/ft transmissivity was reported by Wilmoth (1967) from an aquifer test in the same sandstones.

Northern West Virginia and western Maryland.—In northern West Virginia, Pottsville strata have the highest potential for ground-water development. In the Monongahela River basin, Pottsville wells yield an average 44 gpm (Ward and Wilmoth, 1968). Yields reach a maximum of 250 gpm, valley wells being the highest producers. Transmissivity values from aquifer tests reached a maximum of 10,000 gpd/ft. The Pottsville contains saltwater west of a line from Morgantown in Monongalia County to Buckhannon in Upshur County.

A ground-water study of eastern Monongalia County by Quagliotti (1974) revealed an average Pottsville sandstone well yield of 57 gpm. Major aquifers were found throughout the Pottsville Group, but the lower Pottsville had the highest potential.

Allegheny Formation sandstones provide adequate water for small to moderate industrial and public drinking supplies (Ward and Wilmoth, 1968). As in other Pennsylvanian strata, well yields in the Allegheny generally decrease from east to west in northern West Virginia. Average yields ranged from 31 gpm in eastern Monongalia County (Quagliotti, 1974) to 26 gpm over the entire Monongahela River basin (Ward and Wilmoth, 1968). In the Little Kanawha River basin, Allegheny well yields were less, but no average was reported (Bain and Friel, 1972). All the highest yielding Allegheny wells were in valleys underlain by thick sandstone beds. A 27,000-gpd/ft transmissivity was determined from an aquifer test in Allegheny strata in Taylor County (Ward and Wilmoth, 1968).

Several Conemaugh Group sandstone units are considered to be aquifers in northern West Virginia and western Maryland. Well yields average about 10 gpm, but transmissivities are generally less than 1,000 gpd/ft. Basal Conemaugh sands contain saltwater in the western part of the Monongahela River basin (Wilmoth, 1966), and because of mining and drilling activity, poor quality water is found as far east as eastern Harrison County (Nace and Bieber, 1958).

Wells producing from Monongahela strata generally have low yields. Mining activity throughout northern West Virginia and western Maryland has drained much of the Monongahela Group, particularly in outcrop areas.

Basal Dunkard sandstones are the most important Permo-Pennsylvanian-age aquifers in Harrison County (Nace and Bieber, 1958) and the Little Kanawha River basin (Bain and Friel, 1972). Wells in the Dunkard Group average 13 gpm in the Monongahela River basin and 6 gpm in Mason and Putnam Counties (Wilmoth, 1966). The Dunkard is contaminated locally with saltwater from old oil wells. It also feeds many springs with freshwater. In Wetzel County, Dunkard wells close to mapped fracture traces had significantly higher yields than did other wells (Sole and others, 1976).

MISSISSIPPIAN SYSTEM

LITHOSTRATIGRAPHY

Lithologically, the Mississippian System may be divided into three parts (fig. 6): (1) Lower sandstone (Pocono Formation) and overlying red shale (Maccrady Formation), (2) middle limestone (Greenbrier Group), and (3) upper red shale (Mauch Chunk Group). Mississippian strata crop out in or underlie all West Virginia counties (except Jefferson), but important exposures—including many type sections—occur only along the eastern part of the State (fig. 6).

Cooper (1948, p. 258), pleading for future investigations, claimed that in the central Appalachians, geologists will find "some of the thickest and most varied sections of the Mississippian. * * *" Moreover, in Virginia and West Virginia, "the system therein probably contains the fullest Mississippian section on the North American continent." Indeed, the Mauch Chunk and Maccrady red beds are extraordinarily thick and extensive, whereas the Greenbrier limestones reflect the final major marine flooding of the region. Yet so little published work on the Mississippian of the State is available!

For this reason, most stratigraphic data in this paper are from West Virginia Geological Survey County Geologic Reports published between 1907 and 1939 and from more recent unpublished graduate theses. Also, Dennison and Wheeler (1975)

SYSTEM	SERIES	SOUTHEAST GROUP	SOUTHEAST FORMATION	NORTH FORMATION
MISSISSIPPIAN	Chesterian	Mauch Chunk	Bluestone Formation[1]	Mauch Chunk Formation
			Princeton Sandstone	
			Hinton Formation	?
			Bluefield Formation	Greenbrier Limestone
		Greenbrier	Alderson Limestone	
			Greenville Shale	
			Union Limestone	
			Pickaway Limestone	
			Taggard Formation	
	Meramecian		Denmar Formation	Pocono Formation
			Hillsdale Limestone	
	Osagean		Maccrady Formation[2]	
	Kinderhookian		Pocono Formation	Hampshire Formation[3]

[1]In extreme southern West Virginia, uppermost beds of Bluestone Formation are Pennsylvanian

[2]Lower Maccrady Formation may be Osagean

[3]Most of Hampshire Formation is Devonian

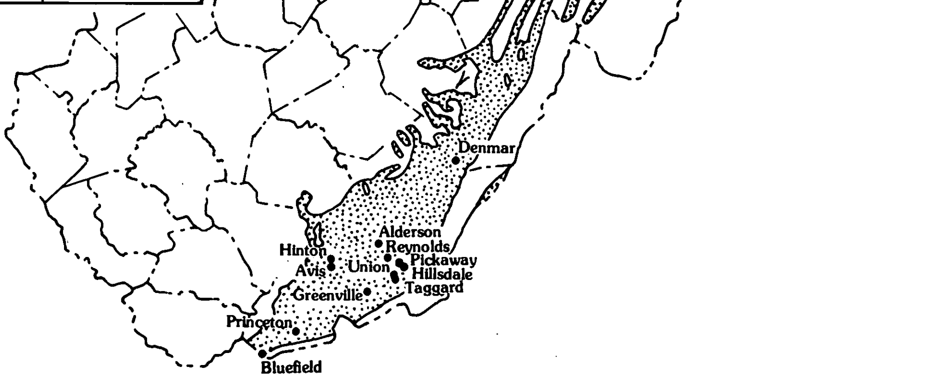

FIGURE 6.—Outcrop of the Mississippian (stippled) and type sections in West Virginia and Maryland.

have provided a general review of fluvial Mississippian strata of the southeastern United States.

SYSTEMIC BOUNDARIES

With only limited paleontological evidence, the Mississippian System base is traditionally put at the base of the Pocono Formation. The Berea Sandstone Member is the basal subdivision of the Pocono in the subsurface and consequently is considered to be the basal Mississippian stratigraphic unit, established solely as a convenient lithologic marker.

Throughout most of West Virginia, lowest Pocono rocks intertongue with Upper Devonian Hampshire (Catskill) Formation red beds. The interpretation follows that the time boundary is not coincident with a lithologic boundary, and Dally (1956) thought the upper Hampshire to be partly of Mississippian age. In the southernmost counties, however, the Pocono grades downward into the Upper Devonian Chemung Group, the boundary being vaguely placed where thick beds of crossbedded, conglomeratic Pocono sandstone rest on flaggy beds of Chemung sandstone.

The Mississippian upper boundary clearly coincides with a marked erosional unconformity. From southeast to northwest across the State, the Pennsylvanian Pottsville Group rests on successively older units of the Mississippian Mauch Chunk Group. In fact, pre-Pottsville erosion removed the entire Mauch Chunk and part to all of the Greenbrier in north-central and western West Virginia (Youse, 1964). In Hancock County (northern panhandle), the Pottsville sits directly on the Pocono Formation. Only in very southern West Virginia is the Mississippian-Pennsylvanian contact conformable. Along the West Virginia/Virginia State line, lowest Pottsville sandstones from the southeast intertongue with variegated Mauch Chunk shale and siltstone to the northwest (England and others, 1976). The uppermost Mauch Chunk beds there are of Pennsylvanian age.

TECTONIC INFLUENCE ON SEDIMENTATION

Tectonism concurrent with sedimentation is illustrated by (1) the pronounced subsidence of the southern basin and (2) the enormous volume of detritus in the Appalachian basin. In the southern basin, as much as 1,700 m (5,576 ft) of continental and shallow-marine sediments was deposited (fig. 7); simultaneously, less than 300 m (984 ft) was laid down on a relatively stable shelf in the northwestern two-thirds of the State. In between, the Mississippian System thickens notably over a short distance (hinge line). In the Appalachian basin, combined uplift and erosion of an eastern landmass supplied the enormous volume of detritus, including the molasse facies of the Pocono (Dally, 1956) and Mauch Chunk (Hoque, 1968). In southern West Virginia and Virginia, polymictic conglomerates of the Princeton Sandstone (Mauch Chunk Group) have been identified as reworked Silurian, Devonian, and Mississippian sediments (Thomas, 1966).

POCONO FORMATION

The Pocono Formation has been mapped throughout the eastern outcrop belt, but subdivisions are generally thin and cannot be traced from one region to the next. Only in the extreme eastern panhandle are mappable units within the Pocono distinguished; hence, where the Rockwell, Purslane, and Hedges Formations (in ascending order) can be distinguished, the Pocono is raised to the rank of "group."

The thickest Pocono Group section is in Berkeley County, where it totals 335 m (1,099 ft); it thins to

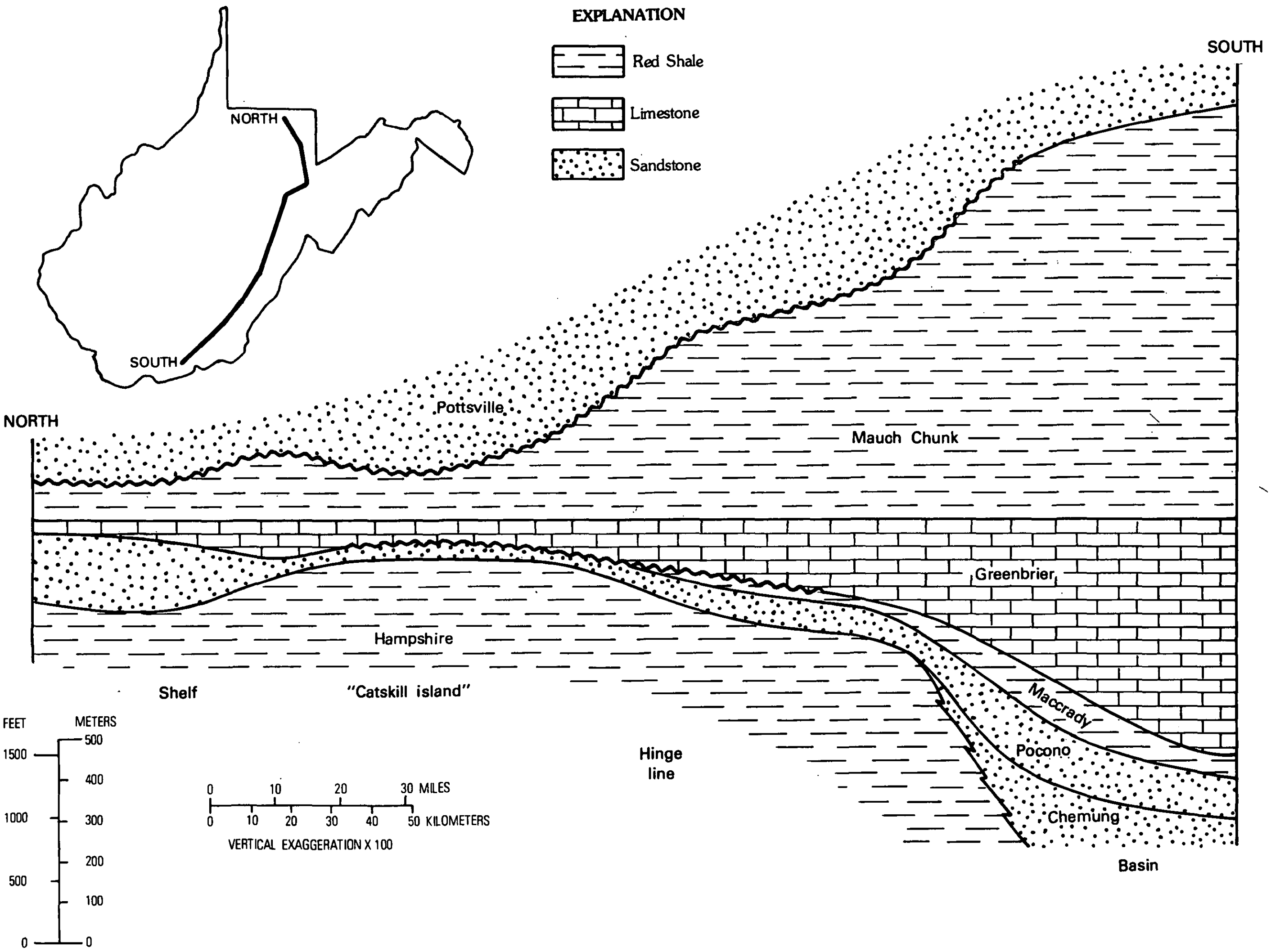

FIGURE 7.—Cross section of Mississippian strata along outcrop belt.

150 m (492 ft) to the southwest in Hampshire and Hardy Counties. The Rockwell Formation includes interbedded arkosic, conglomeratic, and argillaceous sandstone; sandy and silty shale; fine conglomerate; coal; and occasional plant fossils. The Purslane Sandstone is predominantly fine-grained sandstone alternating with conglomerate and some sandy shale; at the top are beds of black shale and coal. The Hedges Formation consists of sandy shale, thin beds of laminated argillaceous sandstone, black shale, and semianthracite coal. Plant fossils have been reported from the black shale in Hampshire County; this unit thins to the southwest and is absent in Hardy County. The upper contact of the Pocono Group is not seen because rocks younger than Pocono are not present in this area.

In southern West Virginia, the Pocono Formation resembles the Pocono Group of the Hampshire-Berkeley County area, except that it is noticeably thinner (fig. 7). The undifferentiated Pocono ranges from 60 to 180 m (197 to 582 ft) in thickness, consisting primarily of brown, coarse-grained and conglomeratic crossbedded sandstone. Sandy shale, some red, and lenses of impure coal and conglomerate are also present. In the southern counties, the Sunbury Shale Member (traced via the subsurface to its type section in Ohio) is a black sandy shale containing minor sandstone; its thickness ranges from 5 to 50 m (16 to 164 ft). Several authors have recognized the basal Berea Sandstone Member (a gas reservoir in the west) in the outcrop. In this area, the upper limit of the Pocono is placed above the coal-bearing strata and below Maccrady Formation red shale or limestone.

The Pocono Formation thins drastically in central West Virginia and actually is missing over a large territory called the "Catskill island" (Figs. 2 and 7). The island was a deltaic lobe, standing above sea level (Dally, 1956). Consequently, an unconformity is present here between the Hampshire (Catskill) Formation and the overlying Greenbrier Limestone.

North of this area, the Pocono Formation progressively thickens, reaching a maximum of 200 m (656 ft) in Monongalia County (the thickening is mostly in the lower part). The unit is predominantly conglomeratic sandstone containing interbedded sandy or calcareous shale, siltstone, rare limestone, and occasional coal streaks (Tucker County only). Coquinas of marine fossils, particularly brachiopods, are scarce in the sandstone beds. The upper contact with limestone of the Greenbrier Formation is sharp.

MACCRADY FORMATION

The Maccrady Formation is restricted to outcrops in the southeastern counties and to the subsurface in the south. Its maximum thickness in the State, 125 m (410 ft), is in Monroe County, but it thickens to the southeast into Virginia (where the type section is situated). The unit thins to the north and northwest and is absent north of Randolph County (fig. 7). On the whole, Maccrady thickness is quite variable, particularly in the subsurface, and indicates an upper erosion surface in those areas where it thins and pinches out (Youse, 1964; Flowers, 1956). The formation consists of red and purple arenaceous shale and siltstone and varying amounts of green and yellow shale, yellow limestone in the upper part, and calcareous sandstone. Minor anhydrite has been reported from these red beds in Wayne, McDowell, and Raleigh Counties.

The Maccrady Formation has received scant geologic attention. Plant fossils are rare, as are marine fossils in the limestone beds. Dennison and Wheeler (1975) considered most of the Maccrady north of Mercer and Monroe Counties to be of marine origin.

GREENBRIER GROUP

Southeastern West Virginia's Greenbrier Group is lithologically complex and very thick. It is dominated by limestone; interbedded shales provide a basis for subdivision. Marine fossils are abundant, and a few strata contain plant fossils. The lowest formation, the Hillsdale, is a cherty, argillaceous limestone which loses its shaly nature and thins to the north, pinching out in Pocahontas County. The overlying Denmar Formation consists of both cherty and oolitic limestone, becoming shaly near the top (Wells, 1950). This shale may be red, calcareous or sandy, and contains plant and marine fossils. The next higher Taggard Formation is distinguished by red and green occasionally sandy shale, interbedded with oolitic limestone. The formation never exceeds 15 m (49 ft) in thickness and is succeeded by the Pickaway Limestone, which has a diverse character —sandy and micritic in some parts and oolitic elsewhere, containing fossiliferous beds and an occasional red streak, and marked by stylolites and characteristic jointing. Like all Greenbrier subdivisions, the Pickaway thins to the north.

Above is the notably oolitic Union Limestone. It is very fossiliferous, and in the middle it is somewhat shaly (red). Both massive and lenticular beds have been reported. The clastic Greenville Shale may or may not be present on top of the Union; it is dark or black, calcareous, and lenticular. The highest

Greenbrier formation is the sandy and oolitic Alderson Limestone.

In Randolph County, the Greenbrier Group changes drastically; it thins to the north, the lower formations pinching out; simultaneously, the facies change. To the south the limestone generally includes more micrite and oolite, whereas the northern Greenbrier contains more clastic (though nonoolitic) limestone (Leonard, 1968).

North of central Randolph County, the Greenbrier has not been divided; hence, its rank is reduced to "Greenbrier Limestone." A threefold division is useful, however: (1) the basal Loyalhanna Member is a crossbedded arenaceous limestone or calcareous sandstone, (2) the middle red and green shale and siltstone, tentatively equated with the Taggard and Pickaway Formations of the south (Leonard, 1968), intertongue with basal Mauch Chunk red beds in Pennsylvania, and (3) the upper, abundantly fossiliferous limestone correlates with the Greenbrier Member of the Mauch Chunk Formation in Pennsylvania. Lithologic correlation with the southern Union and Alderson Formations is questionable.

The basal member in the north-central West Virginia subsurface is a sandy limestone or a calcareous sandstone, typically less than 12 m (39 ft) thick; it has been dolomitized throughout most of this region (Martens and Hoskins, 1948). To the southwest, the basal member is generally oolitic. Oolite distribution was determined by topographic features on the pre-Greenbrier erosional surface (Youse, 1964). Anhydrite traces are commonly found in the lowermost Greenbrier of the southwestern counties.

The Greenbrier Group (Formation) extends across the State, except for small areas along the Ohio River and in most of the eastern panhandle. In northern West Virginia, its thickness ranges from 15 to 30 m (49 to 98 ft), and in the west, from 15 to 45 m (49 to 148 ft); it thickens systematically to a maximum in Mercer County, 550 m (1,804 ft). The upper contact is everywhere gradational with the Mauch Chunk Group in outcrop, there being red shale in the upper part of the Greenbrier Limestone and marine limestone in the lowest Mauch Chunk shale.

MAUCH CHUNK GROUP

Like other major Mississippian stratigraphic units, the Mauch Chunk Group (of prevailing red and variegated shale) has different characteristics in different geographical areas. In the southern basin it is a thicker, more variable group divisible into several formations; in the north and northwest across the hinge line, it is thinner and more uniform (fig. 7).

In Mercer, Monroe, and Summers Counties, the Mauch Chunk Group is almost 1,000 m (3,280 ft) thick, and four formations are recognized. These units are traced as far north as Randolph County, although the total thickness is halved. The lowest third of the oldest (Bluefield) formation is gradational with the underlying Greenbrier, containing interbedded gray and green marine shale and limestone and minor amounts of terrestrial shale and sandstone. An important member, relatively thin but areally extensive, is the Reynolds Limestone. The upper part of the Bluefield contains terrestrial shale and sandstone, mostly red, and some coal and marine and freshwater limestone.

The overlying Hinton Formation is composed of interbedded red, arenaceous, partly calcareous shale and siltstone; ferruginous and calcareous sandstone; many fossiliferous limestone beds; and coal and associated underclay. One significant member is the Avis Limestone, which, like the Reynolds, resembles the Greenbrier in lithology and faunal assemblage. The overlying coarse-grained, pebbly, crossbedded Princeton Sandstone reportedly contains shale and plant fossils. The thickness of this littoral deposit, 6 to 24 m (20 to 79 ft), varies erratically across the southern outcrops.

The youngest formation, the Bluestone (named for the river in Mercer County), is similar to the lowest two Mauch Chunk formations, consisting of red and green calcareous shale and siltstone, variegated sandstone, shaly and lenticular limestone, and coal and underclay. Like the Bluefield and Hinton, the Bluestone yields both plant and marine fossils and represents coastal-plain sedimentation.

North of central Randolph County, undifferentiated red and green shale interbedded with green flaggy sandstone is termed the Mauch Chunk Formation. Thin marine limestone is present near the base. Coal in the northern counties is absent, even though the formation is largely of continental origin. Only sparse plant fossils have been noted. A local conglomerate in Tucker County has been labeled the Princeton Member.

In West Virginia's subsurface, the Mauch Chunk Formation thins westward from 90 m (295 ft) in the central part of the State to nothing in Ritchie and Wood Counties. Overall, such drastic thinning is due to (1) the erosional unconformity at the top of the Mississippian System and (2) the increased distance from the southeastern source of Mississippian clastic materials (Dennison and Wheeler, 1975).

BIOSTRATIGRAPHY AND PALEONTOLOGY

Very little study has been made of Mississippian biostratigraphy (fig. 1) and paleontology in the State since 1950. Most recent papers merely restate age relationships published in older reports.

INVERTEBRATE

On the basis of marine invertebrates, Dally (1956) concluded that the Pocono Formation of the south ranges from the lower Kinderhookian Series through upper Osagean. Simultaneously, the last Devonian Hampshire (Catskill) red beds were being deposited to the north. The marine invertebrate fauna to the north is late Osagean through Meramecian (Dally, 1956), noticeably younger than the southern Pocono fauna.

The Maccrady Formation has traditionally been considered late Osagean to early Meramecian, but Dally (1956) thought the entire Maccrady to be early Meramecian.

Preliminary conodont biostratigraphy (Chaplin, 1971) shows that the Hillsdale Limestone, lowest formation of the southern Greenbrier Group, correlates with the middle Meramecian of the type area. According to Wells (1950), the Hillsdale and Denmar Formations are middle and late Meramecian, respectively, whereas the Taggard Formation straddles the Meramecian-Chesterian boundary. The Pickaway and Union Limestones contain an early Chesterian fauna (Hickman, 1951). The Greenbrier Formation appears to be younger to the north, that is, entirely Chesterian. A late Chesterian pelecypod and endothyroid foraminiferal fauna was identified from the upper Greenbrier Limestone in Monongalia County (Wray, 1952). On the other hand, Uttley (1974) put the lower Loyalhanna Member of northern West Virginia and Pennsylvania in the Meramecian because of the contained conodont elements. He believed that the rest of the Greenbrier Limestone was Chesterian.

The Mauch Chunk, then, is middle to late Chesterian. Middle Chesterian conodonts were recovered from the Bluefield Formation by Rexroad and Clarke (1960). In southern West Virginia, Englund and others (1976) reported a (late?) Chesterian marine invertebrate fauna from a calcareous siltstone near the top of the Bluestone Formation; the overlying member of shale and siltstone (also of the Bluestone) intertongues with the Pennsylvanian Pottsville Group. In Mercer County, where the Mississippian-Pennsylvanian contact is gradational, the uppermost Mauch Chunk beds (perhaps 15 m, 49 ft) are of Pennsylvanian age.

VERTEBRATE

Carboniferous vertebrate biostratigraphy is an uncertain art at best, made difficult by scarce material, consisting principally of isolated chondrichthyan teeth and scales. Ample evidence exists that most Carboniferous chondrichthyans, particularly among the bradyodonts, had heterodont dentitions, but articulated dentitions with associations of tooth "species" are very rare.

Extensive early work, but no recent revision, has been done on the lower Carboniferous of the central United States (Newberry and Worthen, 1866; St. John and Worthen, 1875, 1883) and Europe (Davis, 1883; Woodward, 1889).

Early Carboniferous vertebrates from West Virginia are particularly scarce. The area's geologic setting is at the interface between the midcontinental seas and the fluviatile environment of the rising Appalachian mountains, as well as at the junction between the northeastern and southeastern United States Carboniferous coal basins.

At a time when the vertebrate record could provide vital evidence in the study of plate tectonics, it is embarrassing that we know nothing whatsoever about a region of undeformed sediments across the center of the possible dispersal route among European, North American, and Gondwanaland faunas.

The following discussion is based of necessity upon limited collections in the Carnegie Museum, Pittsburgh, Pa.

Marine.—The basal Mississippian Pocono Group and Maccrady Formation have yielded only occasional unidentified bone and scale fragments. However, the Greenbrier Group contains useful fossils. Two chondrichthyan teeth, a petalodont and an orodont, have been found in Benedict's Cave, Greenbrier County. Neither can be presently identified to genus. Isolated fish teeth and spines become rarer southward. The spine, *Physonemus falcatus* (St. John and Worthen, 1883), from about 27 m (90 ft) below the top of the Greenbrier in the Acme quarries at Alderson, and the tooth, *Poecilodus st. ludovicii* (St. John and Worthen, 1883), from the top of the Greenbrier at the Savannah Lane quarries, Lewisburg, are both named from the type St. Louis limestone. *Physonemus falcatus* is abundant in the upper Chesterian Bear limestone of Montana, and *Poecilodus* ranges into the Pennsylvanian (St. John and Worthen, 1883).

The Greenbrier at the Lake Lynn quarry, Fayette County, Pa., yields acanthodian and petalodontiform denticles and a variety of teeth. These are the elasmobranchs *Cladodus* sp. and *Hybocladodus* sp. (mid-Carboniferous), the bradyodonts *Venustodus argutus* (Chesterian), *V. leidyi* (also from the type St. Louis limestone), *V. variabilis* (also Burlington limestone of Iowa), *Psephodus crenulatus* (found in the Keokuk limestone), *P. Concolutus* (Burlington limestone), and *Helodus*-like anterior cochliodont teeth. The orodont *Desmiodus tumidus* is known from the Loyalhanna limestone (at Breakneck, Fayette County, Pa.) and the St. Louis limestone, and the acanthodian *Gyracanthus* is present in the Greenbrier of Uniontown, Pa., plus the rest of the world.

At present, we have little basis for faunal differentiation between Meramecian and Chesterian vertebrates, either in the upper Greenbrier or elsewhere. Possibly, if additional prospecting is carried out, the lower Greenbrier of southern West Virginia might yield a conspicuously different fauna.

Nonmarine.—The earliest nonmarine West Virginia Mississippian vertebrates are in the Bickett shale, Bluefield Formation, Mauch Chunk Group of Greer, Monongalia County. The anthracosaurian amphibian *Proterogyrinus scheelei* (Romer, 1970) (=*Mauchchunkia bassa*, Hotton, 1970; see Panchen, 1975) and the temnospondylous amphibian *Greererpeton burkemorani* (Romer, 1969) occur with the lungfish *Tranodis castrensis* (Thomson, 1965).

The fauna is similar to that of the British Upper Visean Oil Shale Group (Panchen, 1973, 1975); *Tranodis* also occurs in the type Chesterian. Bone fragments are not uncommon from the Bluefield Formation elsewhere in northern West Virginia. Fragmentary fish and amphibians have been found in the Hinton formation, Mauch Chunk Group (Romer, 1941; Panchen, 1967).

PALEOBOTANY

HISTORY OF STUDY

William B. Rogers was the first professional geologist to study the upper Paleozoic rocks of the area (1835–41). Although his classification was based solely on physical stratigraphy, tempered with economics (Rogers, 1884), he did mention several fossiliferous horizons. The first article on the area's fossil plants was published by two medical doctors (Hildreth and Morton, 1835) at about the same time as Rogers' first report (Gillespie and Latimer, 1961). In the early-to-middle 1850's, Lesquereux collected in the Ohio and Kanawha Valleys; he also studied and described Hildreth's and other collections (Lesquereux, 1858), which he later included in his several-volume summary (Lesquereux, 1880–84). This work also included the first attempt in North America to use plant fossils biostratigraphically. Fontaine and White (1880), in their volume on West Virginia and Pennsylvania Dunkard floras, suggested that Permian rocks might be present, thus initiating a controversy that still is not settled (Barlow, 1975).

Many of David White's pioneering studies (middle 1880's and later) were based on fieldwork in West Virginia. He (White, 1913, 1936) and Darrah (1934) suggested that at least part of the European and Appalachian upper Paleozoic geologic columns were roughly correlative in detail. Jongmans and others (1937, both papers), after collecting in West Virginia in the early 1930's, and Bertrand (1939), after collecting in Pennsylvania at about the same time, agreed with White. As the result of an extensive collecting trip in 1956, Bode (1958) concluded that the similarities between European and American floras were much greater than the differences.

Read and Mamay (1964) established a comprehensive zonation of North American Carboniferous and Permian floras, and Darrah (1969) reviewed the American literature and summarized his extensive personal observations. Remy and Remy (1977) reviewed the literature on North American late Paleozoic floras and compared the results with their version of the European late Paleozoic. The latest studies have been made in conjunction with the U.S. Geological Survey's Pennsylvanian System Stratotype program (Gillespie and Pfefferkorn, 1976, 1977; Pfefferkorn and Gillespie, 1977a, b, c). We have known for years that the great majority of genera and many species of Carboniferous and Permian plant compressions are common to Europe and North America. However, the lack of a readily available, comprehensive, up-to-date reference has resulted in misunderstandings and a lack of attention to floral characterization of chronostratigraphic divisions.

Also, the rarity of Appalachian upper Paleozoic marine horizons has led to correlation problems with the type Permian. Wagner's (1974) work in Spain on the upper Carboniferous indicates a marine invertebrate/plant compression/palynological West European-Russian correlation. It may be possible to extend the results to the American midcontinent using marine faunas, and then to the Appalachians using compression and palynological floras found in terrestrial sediments. This correlation should resolve whether the Autuniun is late Carboniferous or Permian (Havlena, 1975) and, therefore, whether Permian sediments exist in the Appalachians.

The Amerosinian Megaprovince's remarkable similarities probably begin with the Late Devonian *Archaeopteris* and *Rhacophyton* floras. These similarities continue through the late Paleozoic, culminating with the latest Dunkard floras—Late Pennsylvanian or Early Permian.

MISSISSIPPIAN FLORA

In West Virginia, the Early Mississippian or Pocono flora is characterized by *Lepidodendropsis* (Read, 1955). In basal units, *Adiantites* and *Rhodea* are the most commonly associated plants. *Adiantites* is replaced by *Triphyllopteris* in the upper Pocono. Plant fossils are scarce in the Maccrady and marine Greenbrier, although shaly lenses in the upper Greenbrier and Mauch Chunk (Upper Mississippian) usually contain *Fryopsis, Cardiopteridium,* fragmented stems, and megaspore clusters. The upper Mauch Chunk is characterized by a consistently occurring flora dominated by *Stigmaria stellata, Sphenopteris elegans,* and *Sphenophyllum tenerrimum.* This flora, also present in several other Eastern and Midwestern States, is characteristic of the Namurian A.

Thus, the major difference between the European lower and upper Carboniferous and the North American Mississippian and Pennsylvanian is the Namurian A, located at the base of the European upper Carboniferous and at the top of the North American Mississippian (White, 1936; Gillespie and Pfefferkorn, 1977).

PENNSYLVANIAN AND PERMIAN SYSTEMS

LITHOSTRATIGRAPHY

A general map (fig. 8), four cross sections, and two classifications with an incomplete plethora of stratigraphically arranged names, support this discussion of a thick diverse rock section. The cross sections (figs. 9, 11) show representative highly repetitious assemblages of strata typical of the Pennsylvanian and Permian. Selected coals (from a list of 117), a few limestones, argillaceous beds, and sandstones are included in the classifications (figs. 10, 12). Sandstones are found close above most coals, and, except for the Pocahontas-New River sandstone, each sandstone assumes the name of the underlying coal (unless an earlier name has preference, or a special depositional situation exists).

The area of Pennsylvanian-Permian strata is arbitrarily divided into the "older mining district" and the "younger mining district" (fig. 8). The older mining district conforms to an east-northeast-trending geologically older coal basin in southern West Virginia (which swings southwest to include strata in eastern Kentucky, western Virginia, central Tennessee, and northwestern Alabama). The younger mining district generally conforms to a north-northeast-trending geologically younger coal basin in northern West Virginia, western Maryland, southwestern Pennsylvania, eastern Ohio, and northeastern Kentucky (Arkle, 1974, p. 9).

On the east in the Allegheny Mountain Section (fig. 2), the Pottsville Group consists of much quartzose sandstone, some subgraywacke, argillaceous beds, and irregular thin coal beds; subdivision is difficult. As the unit thickens to the south-southeast, the quartzose sandstones are confined to upper beds or thin toward southeasternmost exposures; they disappear to the southwest in the State's central Upshur and Webster Counties. The westerly disappearance of the quartzose sandstones trends north in the subsurface into Pennsylvania. On exposures in southeastern West Virginia, Allegheny and Conemaugh strata thin perceptibly, change facies, and lose coals.

The Pottsville Group is composed of subgraywacke and argillaceous beds above an irregular Mississippian surface north of the 61-m (200-ft) isopach in the subsurface of Mason, Wood, and Pleasants Counties of north-central West Virginia (fig. 8). From here, the Pottsville section thickens rapidly to the south-southeast in southwestern West Virginia, and the Allegheny Formation loses identity below Conemaugh red beds. The lithologic characteristics of the subsurface section, based on limited data, are a thin replica of the thickening exposed section to the south.

OLDER MINING DISTRICT

Sediments from a southerly source were deposited in a rapidly but intermittently subsiding basin in southern West Virginia. Little paleogeographic change took place during Mississippian and early Pennsylvanian time. Source materials became coarser and more abundant, and the paleoclimate fostered extensive flora growth and plant-debris preservation in a chemically reducing environment during deposition.

The district includes the Pocahontas, New River, and Kanawha Formations and the Charleston Sandstone Group; these units have a maximum cumula-

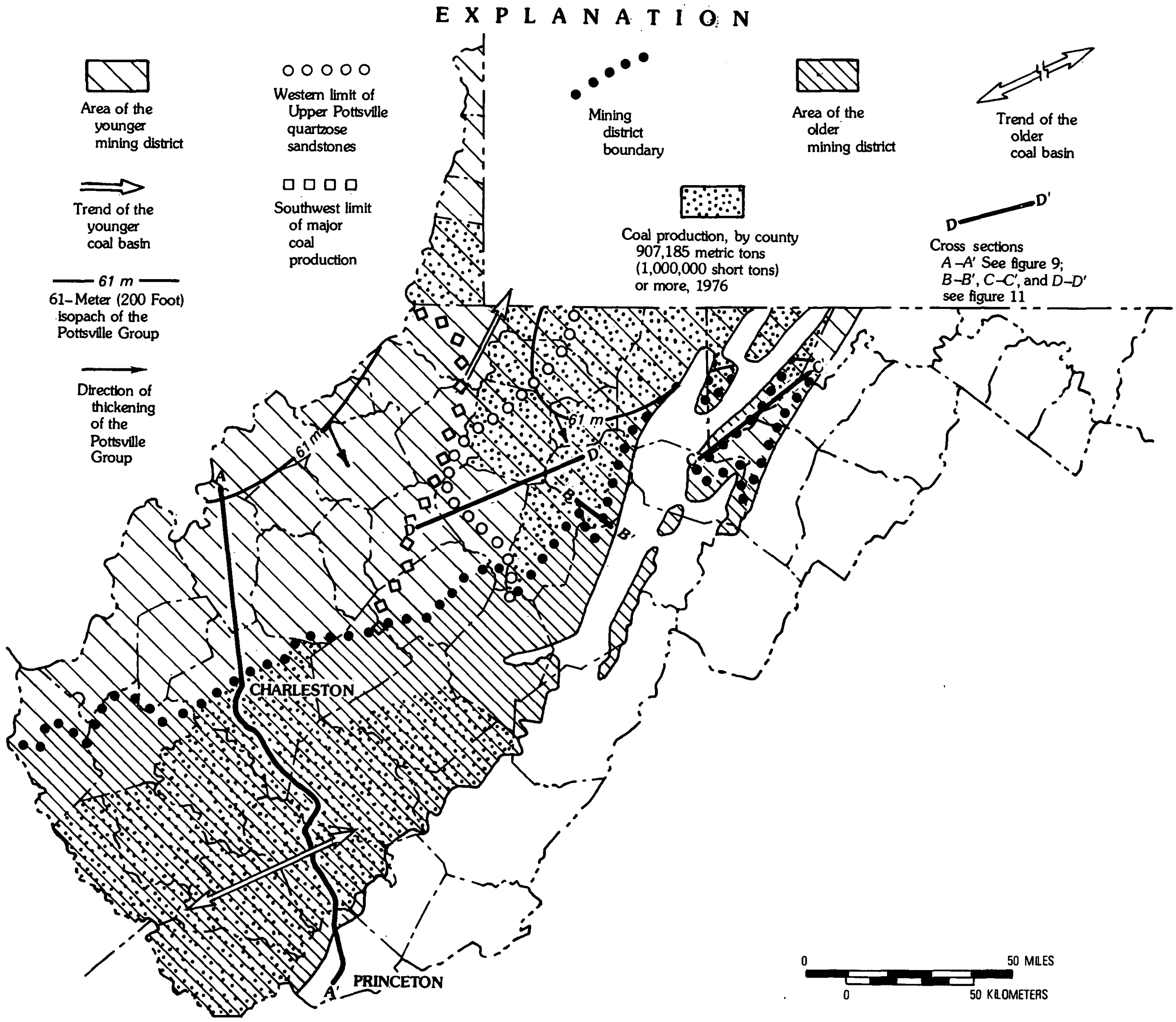

FIGURE 8.—Basin trends and coal-mining features of Pennsylvanian-Permian strata in West Virginia and Maryland.

tive thickness of about 1,326 m (4,350 ft). (The older term "Charleston Sandstone Group" (Campbell, 1901, p. 5) informally describes the lithostratigraphy without regard to time-rock relationships, which are currently being studied by the USGS in connection with the stratotype section project for the Ninth International Carboniferous Congress.) The younger mining district of northern and western West Virginia includes the Pottsville, Allegheny, Conemaugh, Monongahela, and Dunkard Groups; these units have a maximum cumulative thickness of about 914 m (3,000 ft) (fig. 1). Strata of the upper Pottsville, Allegheny, and possibly the lower Conemaugh to the north have a facies relationship with the essentially subgraywacke Charleston Sandstone Group sequence to the south.

The boundary between mining districts is the surface expression of an atypical north-northwest-thinning section of the older mining district, subjacent to the east-southeast-thinning of an atypical section of the younger mining district. In the north, the division is the base of the upper Pottsville quartzose sandstones; farther southwest, it is the Conemaugh red-beds base and the top of the Charleston Sandstone Group.

The Pottsville Group of the younger mining district was deposited on an irregular Mississippian surface and shows a fairly uniform (although variable) thickness north of the 61-m (200-ft) isopach line in northern West Virginia, in western Maryland, and throughout much of the northern remainder of the Appalachian coal field.

Younger strata of the Pocahontas and New River Formations were deposited on an irregular older Mississippian surface to the north-northwest (in the direction of thinning). In the subsurface, the New River quartzose sandstone facies was deposited on an irregular Lower Mississippian surface on the Burning Spring anticline of Pleasants, Wood, and Wirt Counties (Flowers, 1956, p. 15). A transition zone between Mississippian and Pennsylvanian time marks a continuous-deposition area on exposures in Mercer and Summers Counties and in the subsurface farther north in McDowell, Wyoming, and Raleigh Counties (Arkle and Latimer, 1961, p. 121; Englund and others, 1977, p. 38, 39).

The coal-bearing facies of the Pocahontas, New River, and Kanawha Formations and the Charleston Sandstone Group is exposed ever farther north-northwest on a broad north-northwest-dipping monocline in ascending the section. Major coals have formed in narrow linear patterns paralleling the east-northeast basinal trend. They are eroded on southeasternmost exposures where many coals are thickest. Coals of the New River Formation and Charleston Sandstone Group thin southeast of their maximum development and possibly disappear in that direction. All coals thin and disappear in ascending order, farther to the northwest.

The Kanawha and Charleston Sandstone section shows that a back-barrier delta environment during Pocahontas and New River time gave way to lower and upper delta-plain environments. Deposition of the Charleston Sandstone Group culminated with deposition of deltaic subgraywacke between the No. 6 Block coal and the base of the Conemaugh redbeds (figs. 9 and 10).

POCAHONTAS FORMATION

The Pocahontas Formation (fig. 10) includes strata from the top of the Mauch Chunk red beds and the base of the lowest Pennsylvanian sandstone to the top of the Flattop Mountain sandstones. A thickness of 216 m (710 ft) can be seen between Pocahontas, Va., and Great Flattop Mountain (at the common corner of McDowell and Mercer Counties, W. Va., and Tazewell County, Va.) (White,

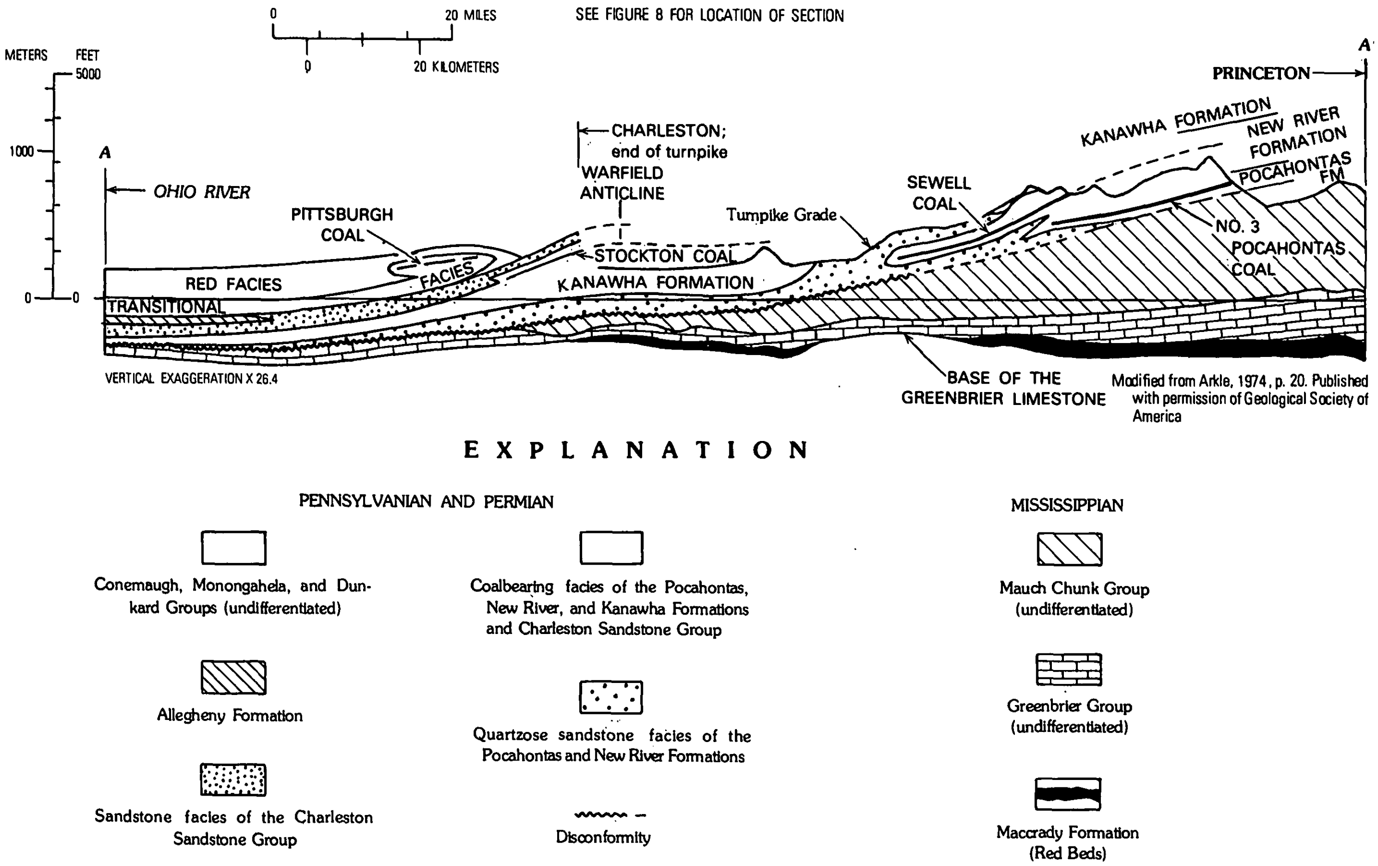

FIGURE 9.—Geologic cross section from the Ohio River to Princeton, W. Va.

Conemaugh Group	
Charleston Sandstone Group 107 m (350 ft maximum)	No. 6 Block coal Upper No. 5 Block coal (North Coalburg) Lower No. 5 Block coal (No. 5 Block) Homewood Sandstone Kanawha Black flint[1] Stockton coal
Kanawha Formation 640 m (2100 ft maximum)	Coalburg coal Winifrede coal Chilton "A" coal Winifrede limestone[1] Chilton coal Hernshaw coal Dingess coal Dingess limestone[1] Seth limestone[1] Cedar Grove coal Alma coal Campbells Creek limestone[1] Peerless coal Campbells Creek coal Powellton coal Stockton limestone[2] Unnamed shale[2] Eagle coal Eagle limestone[1] Lower War Eagle coal Gilbert shale[1] Gilbert coal Douglas coal Douglas sandstone Douglas shale[2]
New River Formation 0 to 314 m (1030 ft)	Nuttall sandstone Skelt shale[2] Hartridge shale[2] Sewell coal ("Pocahontas No. 12") Beckley coal ("Pocahontas No. 11") Quinnimont shale Fire Creek coal ("Pocahontas No. 10") Pocahontas No. 9 coal Pineville sandstone Pocahontas No. 8 coal
Pocahontas Formation 0 to 216 m (710 ft)	Flattop Mountain sandstone Pocahontas No. 6 coal Pocahontas No. 4 coal Unnamed shale[2] Pocahontas No. 3 coal North Fork shale[2] Squire Jim coal
MISSISSIPPIAN SYSTEM	

[1]Marine
[2]Fresh or brackish

FIGURE 10.—Pennsylvanian System selective classification—older mining district (southern West Virginia).

1908, p. 13). The formation thins rapidly to the north-northwest and disappears to the northeast in Greenbrier County, W. Va. (fig. 2).

The Pocahontas is composed of subgraywacke (repetitious, massive, slightly argillaceous, medium grained, and locally conglomeratic) and gray to medium-gray shale intercalated with thin impure underclay and coal. Thin sideritic nodules and lenses are present. Penecontemporaneous slumping and sedimentary features (such as crosslaminations) are common.

Thirteen coals have been named; the Squire Jim is the thickest of four basal coals. Successive coals are the Pocahontas Nos. 1 to 7; 3, 4, and 6 are commercially important. These coals are generally less than 1.8 m (6 ft) thick, although in one area, the Pocahontas No. 3 coal is 3.4–4.5 m (11–15 ft) thick.

Other Pocahontas coals are thinner and more irregular. Most have been surface mined, at least locally. The soft bright metallurgical coals, often multibedded, are low volatile (13.0± percent), low sulfur (0.5+ percent), and have high caloric value (15,000± Btu).

New River and Pocahontas smokeless coals were used in the past on ships because of high caloric values and freedom from spontaneous combustion. They were also used early (1863) for manufacturing weak coke in "beehive" ovens. To enhance coke strength, low-medium volatile coals have been blended for many years with more reactive, high-volatile coking coal in byproduct ovens.

NEW RIVER FORMATION

The New River Formation (fig. 10) includes strata from the top of the Flattop Mountain subgraywacke to the top of the quartzose Nuttall sandstone. A thickness of 314 m (1,030 ft) can be seen along the New River Gorge of Fayette and Summers Counties and on exposures in southern West Virginia (Hennen, 1919, p. 294). In the subsurface to the north-northwest, the Pocahontas(?) and New River Formations are represented by only 106.7 m (350 ft) of quartzose sandstone, which thins rapidly where it is exposed to the northeast and which loses identity farther northwest in Tucker County (fig. 8 and 11, cross section *C–C*).

The formation is composed of subgraywacke (repetitious, massive, slightly argillaceous, medium grained, locally conglomeratic), quartzose sandstone, and gray to medium-gray shale, intercalated with thin impure underclay and coal. Siderite nodules and lenses are present. The 1:1 sandstone/shale ratio increases (in sandstone) perceptibly north-northwest. Medium-scale crosslaminations are common in quartzose sandstones, which are fewer and thinner south-southeast from the type locality.

Sixteen coals are named; successive coals in the basal strata are numbered Pocahontas Nos. 8 and 9 above the Pocahontas Formation, and miners designate the younger commercial Fire Creek, Beckley, and Sewell coals as Pocahontas Nos. 10, 11, and 12, respectively.

The coals' physical and chemical characteristics are similar to those of Pocahontas Formation coals, although they are gradationally higher in volatile matter. Commercial coals are generally <1.8 m (6 ft) thick, although the Fire Creek and Beckley coals are 2.7 m (9 ft) thick locally. Other thinner, less uniform coals have been mined, both underground (in the past) and surface (more recently and extensively). The coals are soft, bright, medium volatile (>18.0+ percent), and low sulfur (0.5+ percent), with 14,500+ Btu caloric values. Correlative coals are fewer and less uniform in the thinning section northeast of Fayette County, where they become high-volatile and low-sulfur metallurgical coals.

KANAWHA FORMATION AND CHARLESTON SANDSTONE GROUP

The Kanawha Formation (fig. 10) includes strata from the top of the Nuttall quartzose sandstone to the base of the Stockton coal or, in its absence, the overlying Kanawha Black Flint. The Charleston Sandstone Group extends upward to the base of the Conemaugh Group red beds.

The Kanawha Formation, 305 m (1,000 ft) thick east of the city of Charleston, thickens to more than 640 m (2,100 ft) on southeastern exposures. The section and coals thin on exposures toward the northeast and lose identity in the subsurface (figs. 8 and 11, cross section *C–C′*).

The Charleston Sandstone Group is 107.7 m (350 ft) thick at Charleston, where basal subgraywacke changes to the coal-bearing facies (figs. 9 and 10) farther southeast. The unit is traceable to Kentucky and loses identity north-northeast in Lewis and Webster Counties (fig. 8).

The Kanawha Formation and Charleston Sandstone Group are complex stratigraphic units, composed of subgraywacke (repetitive, irregular, thin to massive beds, locally conglomeratic) and light to medium-gray shale/mudstone (1:1) intercalated with thin carbonate strata and 42 multibedded coal seams. Above the Winifrede coal, subgraywackes of fine to medium-grained sand in a sideritic/argillaceous-mineral matrix become medium-grained sand in an argillaceous-mineral matrix. The upper Kanawha and Charleston sections are principally subgraywacke, and the coals are thinner or absent as the section passes below drainage on the northwest and on exposures to the southeast in Wyoming and Mingo Counties. Three lacustrine-brackish and six marine limestones, also shale and impure sideritic concentrations, are present below the Winifrede coal. The only exception is the marine Kanawha Black Flint, shale, and siltstone above the Stockton coal. These units occur as thin beds, lenses, and concretionary bodies as much as 0.9 m (3 ft) thick. Underclays are thin or absent in Kanawha/Charleston strata.

Ascending the section, the lower group of 24 coals (to above the Cedar Grove) and the upper group of 18 coals (including the remainder of the Kanawha and Charleston coals) are physically transitional. The lower group is 364 m (1,195 ft) thick (maximum), and the upper group is 326 m (1,070 ft) thick (maximum).

Of the lower coal group, the 11 coals immediately above the Nuttall sandstone are generally minable only in the thickest section in Mingo, McDowell, and Wyoming Counties. Of these, the Douglas and Lower War Eagle are soft bright medium volatile (26.0+ percent) and low sulfur (0.6+ percent), attaining minable thicknesses of >0.6 m (2 ft). Locally, the sulfur content of the Gilbert and associated coals is >1.0 percent. The remaining 13 coals are bright gas-and-coking coals, high volatile (29.0–35.0 percent), sulfur <1.0 percent (but locally as much as 2.0 percent), and 14,500+ Btu. The more important are the Eagle (No. 1 Gas), Powellton, Campbell Creek (No. 2 Gas), Peerless, Alma, and Cedar Grove.

The upper group contains 18 coals. The Hernshaw and Chilton are physically transitional between the soft, bright, high-volatile gas coals (below) and the dull (splint) coal interbedded with thin beds of cannel and ordinary blocky-weathering bituminous coal (above). The transitional coals are chemically similar to those below and above, except that sulfur content is <1.0 to >3.0 percent.

The upper group's principal coals are the locally thick Winifrede, Coalburg, Stockton, and No. 5 Block, all characterized as high-volatile, low-sulfur coals, split into many benches by thin-to-thick shale, clay, and bone partings. These steam coals, 0.9–3.6 m (3–13 ft) thick, resist pulverization from transportation and handling and lose little fuel value in storage. They have been marketed as "Kanawha Splints." In manufacturing coke, the No. 5 Block coal is blended with low-volatile coals.

YOUNGER MINING DISTRICT

Sediments from a southerly source were deposited in a gently subsiding, north-northeast-trending basin in northern West Virginia and western Maryland during Pennsylvanian and Permian times (fig. 8). Lacustrine-swamp-deposit thickness and development suggest that repetitive-strata-assemblage axes (fig. 11), in ascending order, shifted east-southeast from the Dunkard basin axis after Allegheny time to the Allegheny Mountain section (fig. 4) during Conemaugh time. The axes then migrated west during the rest of the Paleozoic deposition. The late Dunkard deposition axis coincided again with the Dunkard basin axis at the end of late Paleozoic time.

Allegheny, Conemaugh, Monogahela, and Dunkard (Washington and Greene formations) strata thin from axes west-northwest into Ohio and east-southeast in northern West Virginia and Maryland. On southeast exposures, Allegheny coals thin and disappear in a facies of gray shale and fine- to medium-grained subgraywacke (figs. 8 and 11, cross section *B–B′*). To the southwest, lacustrine and marine limestone and coal of the Conemaugh and younger strata are transitional with red shale, red mudstone, and increasing percentages of subgraywacke. The transitional facies usually contains thin, areally limited coal, irregular lacustrine and marine limestone, and shale, intercalated with or associated with red shale, mudstone, and subgraywacke (figs. 8, 9, and 11, and cross section *A–A′* and *D–D′*). Subgraywackes coalesce locally in the transitional and red facies to form cliffs more than 30 m (100 ft) thick (Arkle, 1959, p. 122).

A back-barrier environment dominated regionally in Pottsville time, giving way to lower and upper delta-plain environments as late as early Conemaugh time. Although occasional lacustrine-marine and swamp incursions extended south-southwest, terrestrial sediments encroached inexorably north-northeast on a broad coastal plain, as can be seen in ascending the Conemaugh, Monongahela, and Dunkard section.

POTTSVILLE GROUP

Lesley (1876, p. 222, 224) used the name "Pottsville" for 18 m (59 ft) of white sandstone overlying probable Mauch Chunk Umbral red shale and underlying XIII, the Lower Coal Group (Allegheny Formation) in the Boyd's Hill well group near Pittsburgh (fig. 1). He (1876, p. 232) coined the term Pottsville from a town of the same name in the Southern Anthracite coal field of eastern Pennsylvania.

The Pottsville Group (fig. 12) extends from the irregular Mississippian surface to the Brookville coal and Mt. Savage clay directly overlying the Homewood Sandstone. The top of the quartzose Homewood sandstone is normally used as the top of the Pottsville Group in the area of limited exposures in West Virginia (fig. 8), because the Brookville coal and Mt. Savage clay are not identified in northern West Virginia.

Three coals—thin, irregular, and not useful stratigraphically—in the upper 61 m (200 ft) of the

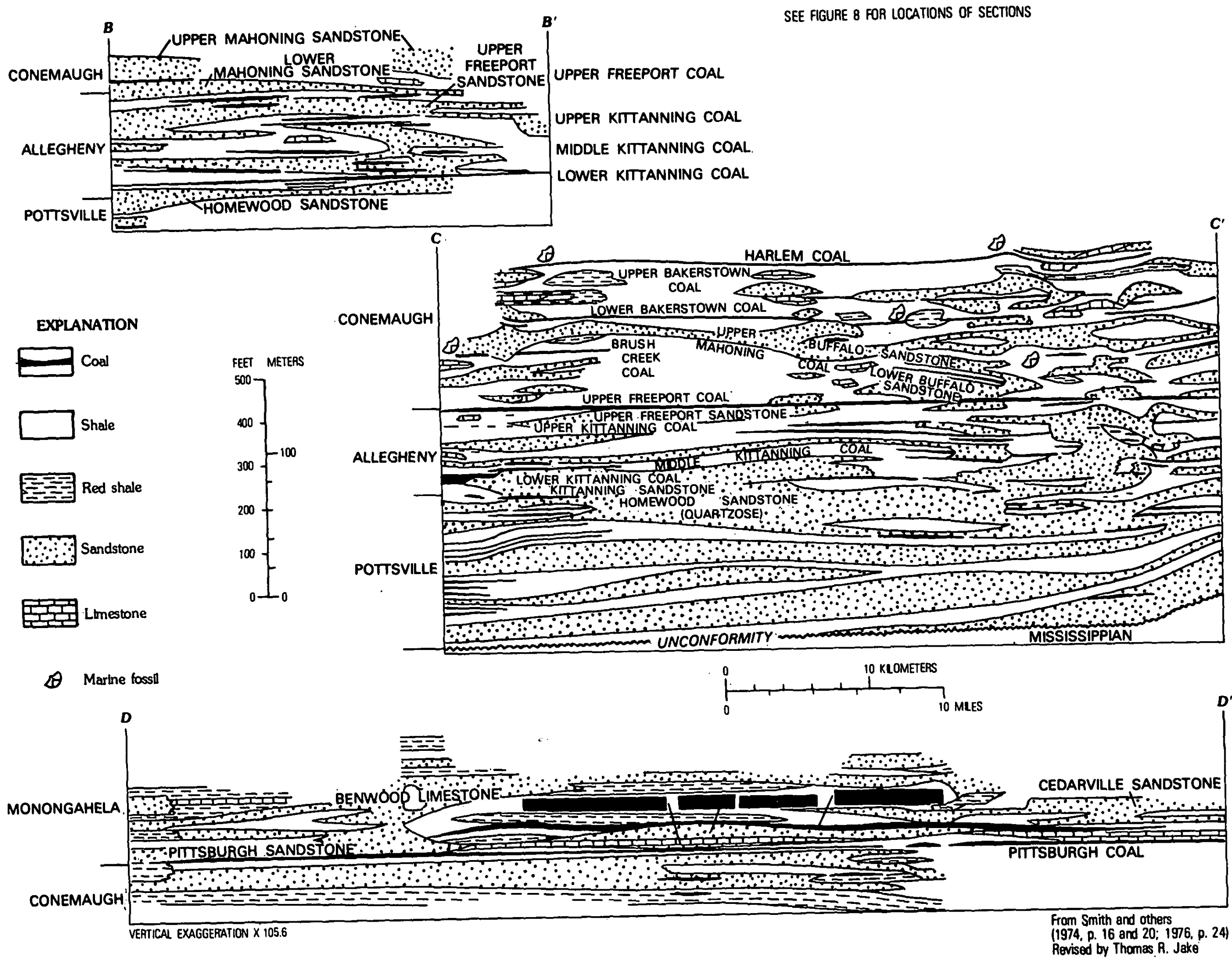

FIGURE 11.—Cross sections showing rock assemblages of the younger mining district.

northern West Virginia Pottsville are described in the southwestern Pennsylvania Pottsville (figs. 8 and 11, cross section *C–C'*).

ALLEGHENY FORMATION

H. D. Rogers (1840) described the Allegheny series in the Allegheny River valley above Pittsburgh, Pa. Stevens (1873, p. 15) redefined the Allegheny to include only those strata between the top of the Homewood sandstone and the base of the Mahoning sandstone (or the top of the Upper Freeport coal). Typical Allegheny strata are exposed above drainage in the Allegheny Mountain section of West Virginia and Maryland, along the Ohio River in Hancock County, on the northern end of the Burning Springs anticline of Pleasants and Wood counties, and on the Tug Fork River, just below Fort Gay, all in West Virginia. The formation is 46 m (125 ft) thick on southeastern exposures in Tucker County, W. Va., more than 61 m (200 ft) thick in Maryland, and about 76 m (250 ft) thick in Hancock County, W. Va.

The Allegheny Formation (fig. 12) is a complex sequence of lenticular, thin- to massive-bedded subgraywacke and light-gray to gray shale and mudstone, intercalated with irregularly thick, low-duty refractory underclay and coal (figs. 8 and 11, cross sections *B–B'* and *C–C'*). Thick deposits of Lower Kittanning and Clarion refractory clay have been mined extensively in Hancock County, W. Va. (two mines at present), and Allegany County, Md. Subgraywacke is locally quartzose in the Allegheny Mountain section of West Virginia and Maryland. Locally, thin lacustrine limestone underlies the Upper Kittanning and younger coal in Preston and Hancock Counties, W. Va., and in Maryland. In

END OF THE LATE PALEOZOIC	
Dunkard Group 335 m + (1100 ft)	Proctor sandstone Windy Gap limestone Nineveh coal Nineveh limestone Jollytown sandstone Jollytown coal Hundred sandstone Upper Washington limestone Lower Marietta sandstone Washington coal Waynesburg sandstone Cassville shale—Elm Grove limestone
Monongahela Group 70–122 m + (230–400 ft)	Waynesburg coal Gilboy sandstone Uniontown coal Benwood limestone Sewickley coal Redstone coal Redstone limestone Upper Pittsburgh sandstone Pittsburgh coal
Conemaugh Group 137–259 m (450–850 ft)	Lower Pittsburgh sandstone Elk Lick coal Ames limestone[1] Harlem coal Saltsburg sandstone Woods Run limestone[1] Bakerstown coal Pine Creek limestone[1] Buffalo sandstone Brush Creek limestone[1] Brush Creek coal Mahoning sandstone { Mahoning coal; Thornton fire clay } Uffington shale
Allegheny Formation 30–91 m (100–300 ft)	Upper Freeport coal Bolivar fire clay Upper Freeport sandstone Lower Freeport coal Upper Kittanning coal Washingtonville limestone[1] Middle Kittanning coal Hamden (Columbiana) limestone[1] Lower Kittanning coal Lower Kittanning clay Vanport (Ferriferous) limestone[1] Clarion fire clay
Pottsville Group 15(?)–61 m (50–200 ft)	Homewood sandstone Mercer coal Connoquenessing sandstone Sharon sandstone(?)
MISSISSIPPIAN SYSTEM	

[1]Marine

FIGURE 12.—Pennsylvanian and Permian Systems selective classification—younger mining district (northern West Virginia and Maryland).

lower Allegheny strata, a thin local marine zone in sandstone is exposed on the Burning Springs anticline, and three marine shale horizons are exposed on the Ohio River in Hancock County.

The Lower Kittanning and Upper Freeport coals are mined, both underground and surface (more extensively) in the Allegheny Mountain section. The mining section is often thick (>2.4 m, 8 ft). The coals are separated into benches by irregular, thin to thick partings. West of the Allegheny Mountain section, they are blocky weathering, bright, high volatile (>29.0 percent), high sulfur (>2.0 percent), and have caloric values of 14,000+ Btu. The coals change to medium volatile (20.0–29.0 percent) in Tucker County, W. Va., and become low volatile (<20.0 percent) locally on exposures in Maryland. Locally, the coals are low to medium sulfur (<1.5 percent).

CONEMAUGH GROUP

Platt (1875, p. 8) named the strata (fig. 12) between the Upper Freeport coal and the base of the Pittsburgh coal for the Conemaugh River, a Monongahela tributary. The group thickens from 137 m (450 ft) on the Ohio River to 250 m (850 ft) at the Maryland-West Virginia boundary in Tucker County, W. Va. It thins to 150 m (500 ft) in the Barbour-Randolph-Upshur County area, and apparently to 53 m (350 ft) on exposures in Clay, Kanawha, Lincoln, and Wayne Counties, all in West Virginia.

The Conemaugh Group is composed of red or light-gray to gray shale and mudstone, and thin- to massive-bedded fine- to medium-grained subgraywacke, intercalated with thin beds of marine and lacustrine limestone and thin irregular coals (Allegheny Mountain section excepted). The entire section is transitional, having principally red shale and mudstone; the percentage of subgraywackes perceptably increases to the southwest.

Widespread thin marine limestone and associated thicker shale were deposited during Brush Creek, Pine Creek, Woods Run, and Ames times in the lower part of the Conemaugh in western and northern West Virginia. No marine strata are evident on exposures in Braxton, Clay, Kanawha, or Lincoln Counties (fig. 2).

The Mahoning and Bakerstown coals, <1.8 m (6 ft) thick, have been underground mined. The Mahoning, Brush Creek, Bakerstown, Harlem, Elk Lick, Little Clarksburg, and Little Pittsburgh coals have been surface mined. Conemaugh coals are blocky weathering, bright and dull banded, high volatile (>35.0 percent), high sulfur (>2.0 percent), and have caloric values of 14,000+ Btu. Volatility decreases to 15.0 percent in the Allegheny Mountain section, where the coals are low to medium sulfur. The Bakerstown coal has <1.0 percent sulfur on the Potomac River in Tucker and Grant Counties.

MONONGAHELA GROUP

This group best shows the lateral transition from terrestrial red beds to lacustrine swamp deposits because of its geographic distribution and the uniformity and thickness of its limestone and coal (figs. 8 and 11, cross section *D–D′*).

H. D. Rogers (1840, p. 150) named the strata for the Monongahela River where they cropped out near Pittsburgh, Pa. Stevenson (1873, p. 15) redefined the group to include those strata between the base of Pittsburgh coal and Waynesburg sandstone (fig. 12). Fontaine and White (1880, p. 105–120), describing fossils with Permian affinities in the Cassville shale below the Waynesburg sandstone, placed the Pennsylvanian-Permian boundary atop the Waynesburg coal.

The group is 76 m (250 ft) thick on the Ohio River, 122 m (400 ft) thick on the Monongahela River, and 107 m (350 ft) thick at one locality in the Allegheny Mountain section of Maryland.

The section is composed of gray shale and mudstone, thin- to massive-bedded subgraywacke, lacustrine limestone, and coal. Gray shale and mudstone are transitional with red shale and mudstone, and subgraywacke increases perceptibly as limestone and coal disappear to the southwest (figs. 8 and 11, cross section *D–D′*). The Redstone, Benwood, and Waynesburg thin-bedded lacustrine limestone and associated thin mudstone are thick carbonate accumulations. The Pittsburgh, Redstone, Sewickley, and Waynesburg coals are widespread in the northern part of the Dunkard basin.

The Pittsburgh coal, accounting for about 24 percent of the State's annual production, is thick and uniform in the Dunkard basin. Only basal beds of the Monongahela Group as high as the Sewickley coal are locally present in upland areas of the Allegheny Mountain section synclines. The mining of a large area of thick Pittsburgh coal in Allegany County, Md., accounted for the early peak (1907) in that State's coal production. The mining section is 1.5 m (5 ft) thick on the Ohio River, 2.7 m (9 ft) thick on the Monongahela River, and 3.6+ m (12 ft) thick in the Allegheny Mountain section.

Monongahela Group coals are blocky weathering, bright and dull banded. The Pittsburgh and Redstone are high volatile and high sulfur (>2.0 percent) and have caloric values of 14,000± Btu. The Redstone is minable only in Barbour, Lewis, and Upshur Counties, in a small area north of Morgantown, and in Mason County. In the Allegheny Mountain section, and in areas contiguous with the section, both coals are locally 1.5 percent sulfur and of metallurgical grade (fig. 3).

The Sewickley coal is similar to the older Pittsburgh and Redstone but generally has a higher sulfur content (>3.0 percent). The three coals notably lack the thick partings prevalent in the Allegheny and upper Kanawha coals. Pittsburgh and Sewickley volatility decreases to 20.0± percent in the Allegheny Mountain section. The thick Waynesburg coal is broken into 0.6–0.9 m (2–3 ft) benches by thin to thick partings. It tends toward high ash (>8.0 percent) and high sulfur (>2.0 percent) content. It is thickest on the Monongahela River, where it is surface mined, and locally in West Virginia's northern panhandle on the Ohio River.

DUNKARD GROUP

The Dunkard Group was described on Dunkard Creek, a Monongahela River tributary in southwestern Pennsylvania (White, 1891, p. 22). It extends from the top of the Waynesburg coal (fig. 12) to above the Windy Gap coal and limestone (which are the youngest swamp lacustrine deposits of the late Paleozoic). The Dunkard Group is more than 335 m (1,100 ft) thick along the Dunkard basin axis in Pennsylvania's southwestern corner and contiguous areas of West Virginia. In recent years, some have placed the base of the Permian at the Washington coal, 30–46 m (100–150 ft) above the Dunkard base. Sedimentation from at least early Conemaugh time continued without interruption to the end of Dunkard deposition.

The Dunkard section, rarely divisible into Washington and Greene Formations in West Virginia, is composed principally of red shale, mudstone, and thin- to massive-bedded graywacke. The Waynesburg "A" (between the Waynesburg sandstone and Washington coal) and Washington coals are high volatile, high ash, and high sulfur. They are associated with gray shale, mudstone, and lacustrine limestone in the basal 30.5–43.7 m (100–150 ft) of the Dunkard Group. They are usually present in northern West Virginia, but are thickest along the Ohio River in one or more benches 0.6–0.9 m (2–3 ft) thick, separated by variable partings. Thin lacustrine limestone, thin coal (<0.3 m or 1 ft), and associated gray beds extend above to the Nineveh limestone only in northern West Virginia. Beginning with the Nineveh, the high Greene limestone and associated coal streaks are exposed in the hilltops along the Ohio River, between the area of greatest thickness in Pennsylvania and Jackson County, W. Va.

BIOSTRATIGRAPHY AND PALEONTOLOGY

INVERTEBRATE

Marine invertebrate faunas in West Virginia's Pennsylvanian rocks are uncommon and, when present, are often composed of long-ranging taxa inappropriate for biostratigraphic work. In addition, the bulk of published papers on the State's Pennsylvanian paleontology is still exploratory and largely taxonomic; detailed biostratigraphy is not available.

The geologically younger mining district in northern and western West Virginia consists of largely Middle and Upper Pennsylvanian rocks similar to those of surrounding States (figs. 2 and 8). It has attracted most researchers because it contains several regional marine intervals and coal of great economic and stratigraphic value. By contrast, the geologically older mining district to the south contains a Lower and Middle Pennsylvanian stratigraphic section dissimilar to that of the north and is complex lithologically. Although the need is greater in the older district, very few researchers have studied faunal elements there.

Older mining district.—The North Fork shale of the Pocahontas Formation contains a local brackish-marine fauna (fig. 10) that has been little studied, and only long-ranging nondiagnostic taxa have been found (Hennen and Gawthrop, 1915). Local brackish-water fossils from the Pocahontas No. 6 coal roof shale (Price, 1916) complete the limited suite of invertebrate fossils from localities in the Pocahontas Formation.

The New River Formation includes local brackish-water faunas in the roof shales of the Sewell and Sewell "B" coals. Durden (1969) placed the Quinnimont shale in the Namurian C (lower Morrowan) on the basis of blattoid insect wings.

The Kanawha Formation contains several marine horizons that have locally abundant, well-preserved faunas. As is true of the lower formations, few studies of Kanawha faunas exist, and most are necessarily preliminary. Lower marine units—Gilbert shale, Eagle limestone, Campbell Creek limestone and Seth limestone—have had almost no attention (Price, 1915, 1916). Cephalopods and crinoids (Furnish and Knapp, 1966; Strimple and Knapp, 1966) place the Dingess and Winifrede limestones in the upper Morrowan (Westphalian B) *Gastrioceras* (cephalopod) zone and the *Stereobrachicrinus* (crinoid) zone. Moore and others (1944) assigned the Winifrede limestone to the lower Atokan *Mesolobus striatus* (brachiopod) zone. Merrill (1973) concluded that the Kanawha Black Flint belonged in the basal Desmoinesian *Cavusgnathus* biofacies of the *Neognathodus* n. sp. B (conondont) zone (upper Westphalian B).

Younger mining district.—Few biostratigraphically useful Pottsville rocks are found in the younger mining district. Durden (1969) studied blattoid wings in shales of the Connoquenessing sandstone, dating them as lower Westphalian B (Morrowan). Brackish-water faunas, found in several places in Pottsville rocks in the Georges Creek-Potomac basin (western Maryland and adjacent West Virginia), have not been studied.

Allegheny rocks in the younger mining district lack continuous marine marker horizons. The Vanport and Hamden limestones are reported locally in northern West Virginia but not in Maryland. Both are considered middle Desmoinesian in surrounding States, on the basis of diagnostic fossils—cephalopods (*Wellerites* zone—Unkelsbay, 1954), fusulinids (*Fusulina* zone—Smyth, 1974), and conodonts (*Neognathodus roundyi* zone—Lane and others, 1971). Insect faunas from the Georges Creek-Potomac basin (Durden, 1969) show the Parker coal (Lower Freeport) to be lower Westphalian D.

Lower Conemaugh rocks contain several important marine zones. The Brush Creek and Ames limestones are useful marker horizons, and the Pine Creek and Woods Run limestones are locally present. They have not been studied in West Virginia, but surrounding States yield excellent faunas. The Brush Creek limestone is basal Missourian, evidenced by cephalopods (*Eothalassoceras* zone—Unklesbay, 1954), fusulinids (*Triticites irregularis* subzone—Smyth, 1974), and conodonts (*Spathognathodus cancellosus/S. elegantulus* zone—Lane and others, 1971). The Woods Run limestone is middle Missourian, evidenced by fusulinid (*Triticites irregularis* subzone—Smyth, 1974) and conodont (*Spathognathodus excelsus/S. gracilus* zone—Lane and others, 1971) data. The Ames limestone is lowermost Virgilian, from its fusulinid (*Triticites cullomanensis* subzone—Wilde, 1975) and conodont (*Spathognathodus elegantulus/S. elongatus* zone—Lane and others, 1971) fossils. Blattoids (Durden, 1969) reinforce this interpretation, together with Stephanian A faunas from the Mason coal (below the Brush Creek coal) and Bakerstown coal, and Stephanian C insects from the freshwater Duquesne limestone (between the Ames limestone and Elk Lick coal).

Neither upper Conemaugh, Monongahela, nor Dunkard beds contain marine fossils. This has created ambiguity in Permo-Carboniferous boundary placement. Correlation attempts have been made using nonmarine invertebrates. Eager (1972) studied upper Monongahela Group freshwater bivalves and concluded that they were more allied to Rotliegendes Permian faunas than to the European upper Carboniferous. Durden (1975) and Tasch (1975) contributed findings on Dunkard blattoids and estheriids, respectively, both concluding that the faunas are distinctively Permian. Indeed, upper Dunkard insects are correlative with the Leonardian of Texas and New Mexico.

VERTEBRATE

Nonmarine Pennsylvanian vertebrates. — West Virginia's Pennsylvanian vertebrates are rare and little studied. The younger mining district vertebrate record has been explored to a limited extent (Lund, 1975, 1976; Olson, 1975), but the older mining district is paleontological terra incognita.

The earliest known Pennsylvanian vertebrates from West Virginia occur near Ansted (southeast of Charleston), at about the level of the Lower Douglas coal (basal Kanawha Formation, Pottsville Group, fig. 10). This is the only known vertebrate horizon from the southeastern coal basin. Investigators to date have uncovered xenacanth shark teeth (*Xenacanthus* sp. cf. *X. triodus*) and *Helodus simplex* spines and a dental battery (Bradyodonti: Helodontiformes) among the chondrichthyans, and *Megalichthyes* scales (Rhipidistia) and a trissolepid near *Sphaerolepis* among the bony fishes.

The *Helodus* material is the first associated dentition of this species from the Western Hemisphere. It was originally reported from Britain's Knowles Ironstone (Moy-Thomas, 1936). Isolated teeth have been reported through the Dunkard in freshwater deposits (Lund, 1975) but are hard to distinguish from the helodontiform anterior teeth of various cochliodonts (Lund, 1976).

The sphaerolepid is a morphological predecessor of fish from the Virgilian Birmingham shale of Pittsburgh (Lund, 1975). These forms are related to but are distinct from *Sphaerolepis*, from the Upper Pennsylvanian of Kounova, Bohemia, Czechoslovakia (Gardiner, 1967).

The Kounova and Pittsburgh specimens have cycloidal scales that have very fine enameloid pectinations and points, whereas the headless Ansted specimen has the distinctive scales only on the lower flank. Nonmarine vertebrate faunas from northern West Virginia, southwestern Pennsylvania, and eastern Ohio are relatively well known and indicate a Virgilian age for rocks from the Conemaugh Group above the Mason shale to the lower half of the Monongahela Group (Lund, 1975), correlating with European Stephanian faunas.

Marine Pennsylvanian vertebrates.—The limited lower and middle Conemaugh marine fauna contains very few identifiable vertebrates. Identifiable remains from the Ames limestone (fig. 12) include acanthodians: *Cladodus* sp. (Chondrichythyes: Elasmobranchii); *Petalodus ohioensis; Janassa strigilina, "Peltodus" transversus, Peripristis semicircularis* (Bradyodonti:Petalodontiformes); the orodont *Chomatodus* sp.; the cochliodont *Deltodus angularis;* and *Physonemus* cf. *P. ancinaciformes* (incertae sedis). Vaughn (1967) described a vertebrate (in certae classis) found in the Ames limestone as well.

The few useful teeth and spines (Romer, 1952; Baird, 1957) roughly indicate a Late Pennsylvanian age, which, surprisingly, agrees with the age of the nonmarine vertebrates. A faunal continuity with the lower Permian is indicated.

Nonmarine Permian vertebrates.—The Benwood limestone (fig. 12) seems to herald a marked, though primarily evolutionary change in the vertebrate fauna. The larger fossil vertebrates from the top of the Benwood limestone through the uppermost Greene Formation beds correspond in detail to Autuniun European faunas as well as to those from the western United States Wolfcamp. The uppermost Greene Formation has possible Leonardian faunal affinities (Lund, 1976; Olson, 1975).

The vertebrates show evolutionary continuity from the Conemaugh through the Dunkard, changing with depositional environment changes as the Pennsylvanian epicontinental sea retreated. There are no faunal discontinuities. The vertebrate record indicates a Wolfcampian age for the Uniontown, Waynesburg, Washington, and Greene formations, and a possible Leonardian age for beds roughly about the Nineveh limestone and above. The Virgilian-Wolfcampian boundary has been classically accepted as the end of the Pennsylvanian (see Introduction and Dunkard Group discussion).

PALEOBOTANY

In West Virginia, the lithostratigraphically prescribed Mississippian/Pennsylvanian boundary is the base of the Bluestone Formation Upper Member, which intertongues with the basal unit of the overlying Pocahontas Formation. The Namurian A flora disappears, and the zone of *Neuropteris pocahontas* begins in the Upper Member. Consequently, the lowermost plant biostratigraphic zone in the Pennsylvanian is defined by *N. pocahontas,* a close relative of *N. schlehani,* the characteristic plant in the lowermost upper Carboniferous of Europe. Some taxonomists believe that these plants may be varieties of the same species (Williams, 1937; Bode, 1958).

Many plant biostratigraphic zones, based on first occurrences and concurrent ranges, are now being established for the remaining upper Paleozoic sediments. They do not coincide exactly with established lithostratigraphic boundaries. More than 200 floras have been collected in West Virginia during the last four field seasons by the U.S. Geological Survey's Pennsylvanian Stratotype Study. These, along with past collections and illustrated reports, indicate that the upper Paleozoic rock sequence in West Virginia is correlative with similarly aged rocks across the United States, and with established Namurian, Westphalian, Stephanian, and Autuniun sequences.

Neuropteris pocahontas generally characterizes basal Pocahontas Formation units. *Lyginopteris* (ranges of *L. stangeri, L. hoeninghausi,* and others, are not firmly established) begins just below the Pocahontas No. 1 coal. *Mariopteris eremopteroides* appears just above the Pocahontas No. 2 coal. *Sphenopteris, Calamites, Alethopteris, Lepidodendron, Sphenophyllum,* and *Asterophyllites* species form other zones in the Pocahontas, although ranges are not completely known. *Neuropteris smithsii,* a large-pinnuled *N. pocahontas* variant, and *Mariopteris pottsvillea, M. eremopteroides* variant, appear near the Pocahontas No. 7 coal.

Important New River Formation additions are *Alethopteris decurrens* near the Beckley coal and *Sphenophyllum cuneifolium, Neuropteris heterophylla, N. obliqua,* and *Asterophyllites equisetiformis* slightly above the Sewell coal. *N. pocahontas* and *N. smithsii* disappear near the Sewell B coal.

The Kanawha Formation base is marked by the appearance of *Neuropteris gigantea* and the end of the lyginopterids and *Alethopteris decurrens.* Other important Kanawha plants are *Alethopteris lonchitica, Annularia radiata, Sphenophyllum majus, S. cuneifolium,* and *S. emarginatum. Neuropteris scheuchzeri* and *N. ovata* appear near the top.

In the lower Allegheny Group (fig. 12), several species disappear: *Alethopteris lonchitica, Neuropteris obliqua, N. heterophylla, N. gigantea, N. rarinervis, Linopteris* spp., *Sphenophyllum cuneifolium,* and *S. majus. S. oblongifolium* appears, pecopterids become more numerous, and *Asolanus camptotaenia* becomes common. The Charleston Group flora is similar. Allegheny floras continue through the Conemaugh Group with more *Sphenophyllum oblongifolium* and increased pecopterid species.

Near the base of the Monongahela Group, the following join with *Neuropteris ovata* and *N. scheuchzeri* as major species: *Alethopteris zeilleri, Danaeides emersonii, Lescuropteris moorei, Nemejeopteris feminaeformis, Pecopteris unita, P. arborescens, Sphenophyllum longifolium, Callipteridium pteridum,* and *C. gigas.* All continue well into the Dunkard Group. Some occur only rarely.

At about the upper Washington limestone horizon, undoubted *Callipteris conferta* is found (Gillespie and others, 1975). Fontaine and White (1880) listed this species from the Washington coal roof shales in Monongalia County, and Darrah (1975) concurred. Bode (1958) believed it to be a different species, probably *C. lyratifolia.* Others, such as *Plagiozamites* cf. *P. planchardi, Walchia,* and *Taeniopteris* sp., have been reported from the upper Conemaugh through the Dunkard (Darrah, 1975), but they are facies-dependent and exceedingly rare.

When these data are compared with those of the European section, several important correlations can be made: (1) the Namurian A is well defined by *Stigmaria stellata, Sphenopteris elegans,* and *Sphenophyllum tenerrimum,* (2) the Westphalian B base is marked by disappearance of the lyginopterids, (3) the Westphalian C is marked by abundance of neuropterids and *Alethopteris lonchitica,* (4) the Westphalian D is marked by the first appearance of *Neuropteris ovata,* and (5) the Stephanian is marked by the beginning of *Sphenophyllum oblongifolium, Alethopteris zeilleri, Nemejeopteris feminaeformis,* and *Callipteridium gigas.* The Autuniun begins with the first occurrence of *Callipteris conferta.*

Several of the historically used biostratigraphic boundaries of Europe can be recognized generally in West Virginia and across North America. The many first-occurrence and concurrent biostratigraphic zones being established in West Virginia will greatly refine the present knowledge for this continent.

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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—

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

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

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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

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Director, U.S. Geological Survey

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