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

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

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ABSTRACT

Kentucky is unique among the States of the Eastern United States in that it contains parts of two major sedimentary basins that have nearly complete successions of Carboniferous rocks. These basins, the Appalachian and Eastern Interior, each contain more than 2,100 m of Mississippian and Pennsylvanian strata.

Carboniferous strata directly underlie four of Kentucky's six principal physiographic regions: the Knobs, Mississippian Plateau, Western Coal Field, and Cumberland Plateau. Weathering and erosion of Carboniferous rocks in these regions have produced a variety of scenic features such as caverns, gorges, natural bridges, and waterfalls.

Mississippian rocks conformably overlie Late Devonian strata and are principally of marine origin. Environments of deposition ranged from relatively deepwater basin to lower delta plain. The Mississippian succession in the State consists of four major lithogenetic groups: (1) distal terrigenous detrital deposits of westward and southward prograding deltaic systems (Kinderhook, Osage); (2) marine carbonate deposits, partly basinal, but dominantly shelf limestone and dolomite (Osage, Meramec); (3) rhythmically alternating marine carbonate and terrigenous detrital deposits, shelf limestone alternating with sandstone and shale from a southward and southwestward prograding delta (Chester); and (4) terrigenous detrital deposits of westward- and southward-prograding deltaic systems (Chester). Major source areas for terrigenous sediments were to the northeast and east of Kentucky. Penecontemporaneous tectonic activity is suggested by distinct variations in the thickness and distribution of units along the trends of major structural features in parts of the State. Some biostratigraphic zones virtually correspond with lithostratigraphic units and serve as practical aids in field identification.

The Mississippian-Pennsylvanian systemic boundary generally is marked by an erosional unconformity, which locally may represent a removal of more than 275 m of Mississippian strata in western Kentucky and more than 60 m in eastern Kentucky. In southeastern Kentucky, deposition was continuous from Late Mississippian into Early Pennsylvanian time. A recently proposed thesis that the Mississippian-Pennsylvanian unconformity in northeastern Kentucky is a depositional or facies boundary is untenable in view of field relationships between lithologic units in the area. The sub-Pennsylvanian surface across east-central and northeastern Kentucky also shows a truncation of progressively older Mississippian strata toward the north.

The Pennsylvanian strata of eastern Kentucky form a clastic wedge that thickens southeastward toward the axis of the Appalachian basin. The rocks are largely deltaic in origin, dominantly thick orthoquartzite in the lower part and siltstone, shale, and relatively thin discontinuous subgraywacke in the upper part. Channel-fill deposits of pebbly orthoquartzite of the Lee Formation (Morrow) form a series of broad lobes generally oriented northeast-southwest, parallel with the axis of the Appalachian basin and with a dominant southwest transport direction. The Breathitt Formation (Morrow, Atoka, Des Moines) consists of siltstone, clay shale, subgraywacke, coal, ironstone, and limestone. It was deposited largely in lower and upper delta-plain environments: tidal flats, interdistributary bays, swamps, and shallow anastomosing stream channels. As many as 30 major coal beds or coal zones are present in the formation. Stratigraphic subdivision of the Breathitt is based on recognition of key beds, particularly marine units, and sequences of key beds. The Conemaugh and Monongahela Formations (Missouri, Virgil) are present in northeastern Kentucky. In contrast with the dark-colored shale of the Breathitt, the Conemaugh and Monongahela are characterized by the presence of red, green, and variegated shale. The formations apparently represent deltaic deposits that were repeatedly inundated by eastward-transgressing seas.

The Pennsylvanian strata of western Kentucky in the southern part of the Eastern Interior basin also are largely deltaic in origin. Their lithology is similar to that of the Lee and Breathitt Formations of eastern Kentucky except that marine limestones, representing as many as 35 transgressions, form a larger part of the succession. About 24 principal coal beds or coal zones have been identified in western Kentucky. Limestones are important key beds for stratigraphic subdivision, but the most useful marker bed is the No. 11 coal bed which has a distinctive clay shale parting. Subsidence was relatively uniform across the basin during Early and Middle Pennsylvanian time; the alternation of shallow marine and deltaic deposits probably is related to the shifting of southward and southwestward prograding delta lobes.

Carboniferous rocks are the major source of mineral resources in Kentucky. The State currently is the leading producer of bituminous coal in the United States and has an estimated original reserve of about 65.6×10^9 metric tons of

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high-voltatile A and B bituminous coal in the Pennsylvanian deposits of eastern and western Kentucky. A large percentage of the oil, natural gas, and industrial and metalic minerals produced in the State has come from Carboniferous rocks.

INTRODUCTION

Carboniferous strata underlie and crop out in about two-thirds of the surface area of Kentucky (fig. 1). The State is unique in the Eastern United States because it contains parts of two major sedimentary basins that have nearly complete successions of Carboniferous rocks. These basins, the Appalachian and the Eastern Interior, though different in their tectonic and depositional histories, each contain more than 2,100 m of Carboniferous strata in Kentucky representing both the Mississippian and Pennsylvanian Systems. The basins are linked by a belt of lower Carboniferous rocks (Mississippian Osage and Meramec ages) extending across the Cincinnati arch in south-central Kentucky. Mississippian rocks (mainly limestone, sandstone, shale, and siltstone) are dominantly marine in origin, and Pennsylvanian rocks (mainly sandstone, siltstone, shale, and coal) are dominantly of deltaic and fluvial origin.

Carboniferous rocks are the major source of mineral resources in Kentucky. The State currently is the leading producer of bituminous coal in the United States, producing from Pennsylvanian deposits in both the Appalachian and Eastern Interior basins—the eastern and western Kentucky coal fields, respectively. Carboniferous units are also a principal source of petroleum, natural gas, limestone, sandstone, shale, clay, fluorspar, sphalerite, galena, barite, and, formerly, iron ore.

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 current usage of the Kentucky Geological Survey.

PHYSIOGRAPHY

Carboniferous strata directly underlie four of Kentucky's six principal physiographic regions: the Knobs, Mississippian Plateau, Western Coal Field, and Cumberland Plateau (fig. 2). The other regions in the State are the Blue Grass, underlain by Ordovician, Silurian, and Devonian rocks, and the Mississippi Embayment where Cretaceous and Tertiary sedimentary deposits rest on Paleozoic rocks.

The Knobs region is a narrow, arcuate belt of conical hills, or knobs, around the outer border of the Blue Grass region. The Knobs are erosional remnants, consisting of Mississippian (Osage) shale and siltstone, which occur along the front of the Pottsville escarpment across east-central Kentucky and along the front of Muldraughs Hill across west-central and south-central Kentucky. Muldraughs Hill is a limestone-capped escarpment bordering the

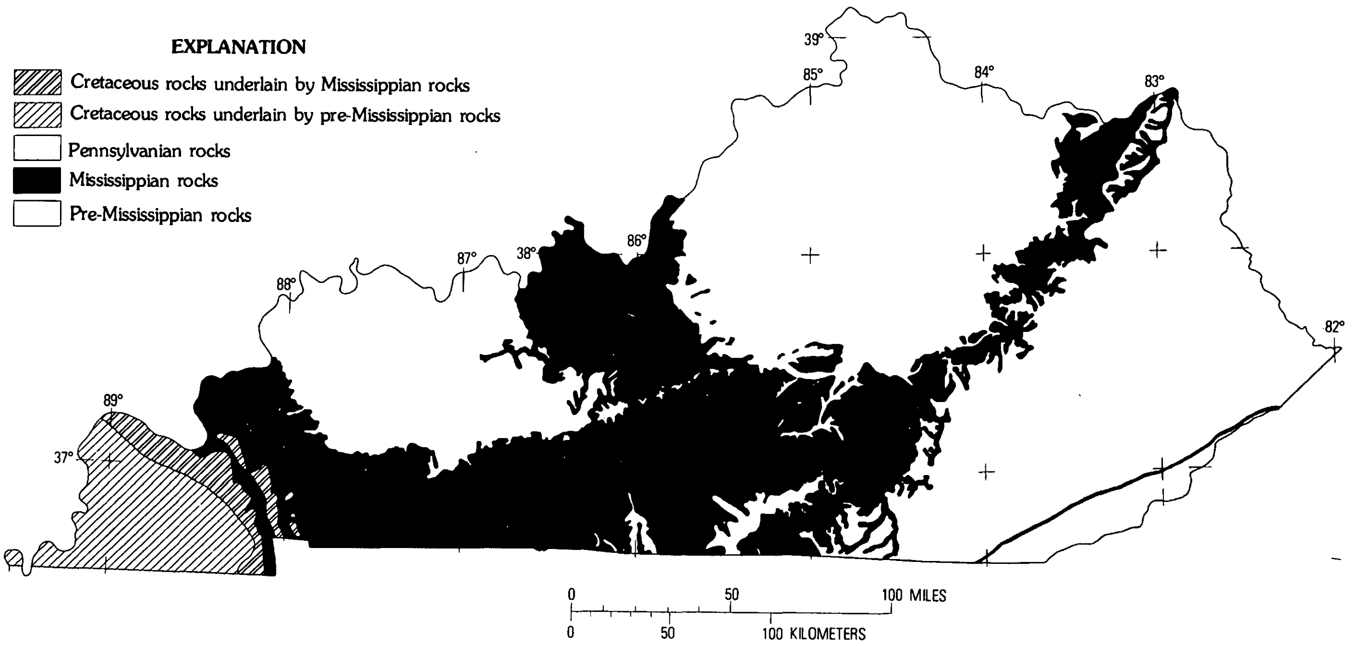

FIGURE 1.—Geologic map of Kentucky showing distribution of Carboniferous rocks.

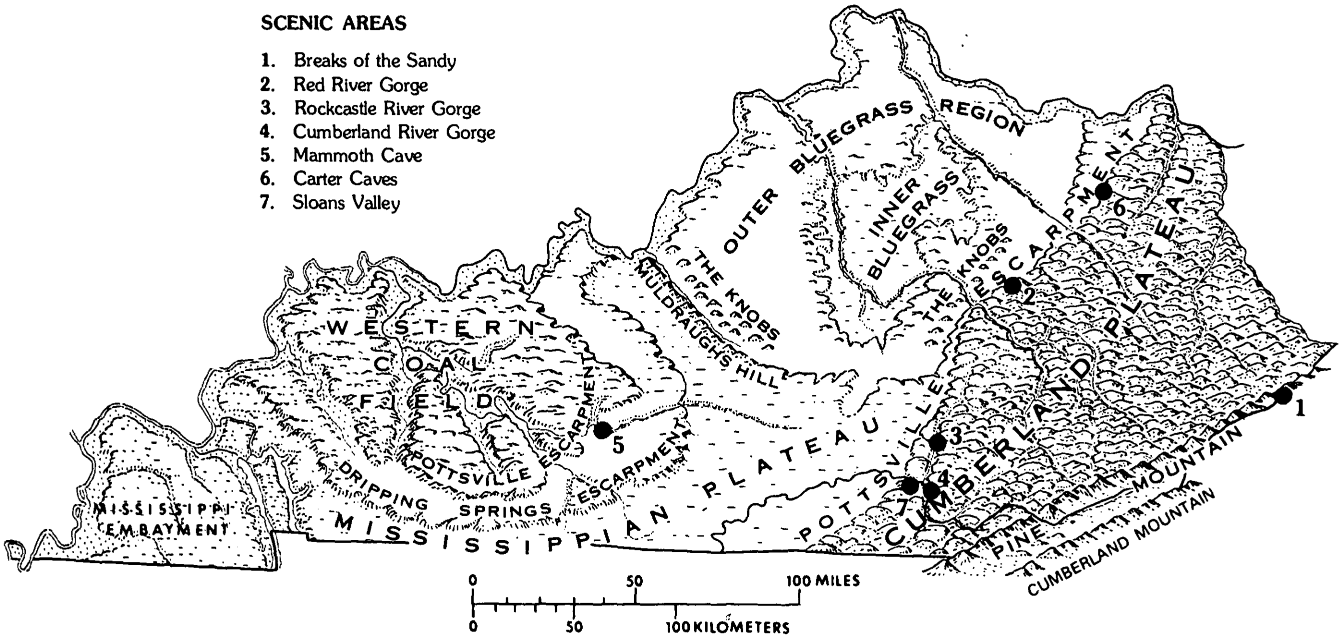

FIGURE 2.—Physiographic diagram of Kentucky (From Lobeck, 1929), showing the location of scenic areas.

Mississippian Plateau region; the Pottsville escarpment, capped by Lower Pennsylvanian sandstone, borders the Cumberland Plateau.

The Mississippian Plateau forms a broad, arcuate belt around the Western Coal Field and extends eastward to the Pottsville escarpment. It consists of two principal parts divided by the Dripping Springs escarpment, an east- and south-facing ridge generally capped by the Big Clifty Sandstone Member of the Golconda Formation (Chester). The outer part is a broad plain with extensive karst development underlain mostly by the St. Louis and Ste. Genevieve Limestones (Meramec). The inner part of the plateau is a dissected upland of moderate relief underlain by limestone, sandstone, and shale of Chester age.

The Western Coal Field is a gently rolling to hilly upland dissected by streams occupying broad, very flat, poorly drained and often swampy valleys. Two major rivers drain the area; one has its headwaters in the coal field. The area is underlain by Pennsylvanian (Morrow-Virgil) shale, sandstone, limestone, and coal. Deep weathering has made natural exposures sparse except along the margins of the basin where streams have cut into the older and generally more resistant Lower Pennsylvanian rocks. Sandstone of the Caseyville Formation (Morrow) forms prominent ridges and cliffs along parts of the border of the coal field, and these constitute the Pottsville escarpment of that area.

The Cumberland Plateau, which is underlain by Pennsylvanian (Morrow-Virgil) shale, sandstone, and coal, is an intricately dissected upland of concordant sharp ridges and V-shaped valleys. It is bordered on the west by the Pottsville escarpment. Lower Pennsylvanian (Morrow) sandstone, overlain by less resistant shale, locally forms broad uplands of little relief along the south-central and southwest border of the plateau. Pine and Cumberland Mountains, two northeast-trending ridges also capped by Lower Pennsylvanian (Morrow) sandstone, border the plateau on the southeast. Four rivers drain the area, three of which have their headwaters generally in or near Pine and Cumberland Mountains where local relief is as much as 700 m.

SCENIC FEATURES

Weathering and erosion of Carboniferous rocks in Kentucky have produced a variety of scenic features of interest to both laymen and geologists (McFarlan, 1958). Many of these features are available to the general public and have been incorporated into State and National parks (fig. 2). Some of the most spectacular scenery in the State is found in the Breaks of the Sandy, a gorge cut through the north end of Pine Mountain by the Russell Fork of the Big Sandy River (McGrain, 1975), and in the gorges of the Red, Rockcastle, and Cumberland Rivers and South Fork of the Cumberland River along the western border of the Cumberland Plateau. Many natural bridges have formed in narrow, sandstone-capped divides, particularly in the Red River area (McFarlan, 1954), and many waterfalls, including the 20-m Cumberland Falls (McGrain, 1955), have formed on resistant Pennsylvanian sandstone.

The Mississippian Plateau of western Kentucky is a classic karst region, containing a broad sinkhole plain and extensive systems of underground drainage and caverns, including the Mammoth Cave-Flint Ridge cave system, formed in the St. Louis and Ste. Genevieve Limestones, and Girkin Formation (Mississippian) (Liversay, 1953). In eastern Kentucky, caves that have formed locally in the Mississippian limestone northwest of the Pottsville escarpment include the Carter and Cascade Caves in the northern part of the area (McGrain, 1954) and those in the Sloans Valley system near the south border of the State (Malott and McGrain, 1977).

The conical hills of the Knobs, remnants of the uplands behind the retreating Muldraughs Hill and Pottsville escarpment, form a striking example of an erosional landscape (McGrain, 1967).

Many exposures of Carboniferous rocks can be found in roadcuts along major Federal and State highways, in strip mines of the eastern and western coal fields, and in limestone quarries. (See, for example, Dever and McGrain, 1969; Smith and others, 1969, 1971; Stokley and McFarlan, 1952). Extensive exposures of complex Pennsylvanian deltaic sequences of shale, sandstone, and coal are found in roadcuts as much as 100 m high in eastern Kentucky, particularly along U.S. Highway 23 in the vicinity of Pikeville.

GENERAL HISTORY OF THE CARBONIFEROUS

The Carboniferous periods in Kentucky have generally been treated as three separate topics: the Mississippian and the Pennsylvanian of eastern Kentucky and the Pennsylvanian of western Kentucky.

Miller (1919, p. 94–141), in the first comprehensive synthesis of the geology of Kentucky, cited early work on Mississippian rocks by D. D. Owen, A. F. Foerste, E. O. Ulrich, Charles Butts, Stuart Weller, and others. These pioneer efforts were followed by systematic studies of Mississippian rocks in Kentucky and adjacent States by Butts (1917, 1922), Ulrich (1917), Stockdale (1939), and by several State surveys in a cooperative plan for geologic mapping along the borders of the Eastern Interior basin (Weller and Sutton, 1940). McFarlan (1943, p. 57–95), incorporated results of these later studies in an expanded revision of Miller's earlier synthesis. Definitions and correlations of Upper Mississippian rock units in western Kentucky were refined by Stouder (1941) and McFarlan and others (1955), and in eastern Kentucky by McFarlan and Walker (1956).

The first usable subdivision of the Pennsylvanian strata of eastern Kentucky was made by Campbell. He named the Lee Formation in the Cumberland Mountains (1893) and later described the formation in exposures near the Pottsville escarpment (1898), giving the name Breathitt Formation to the overlying Pennsylvanian rocks. In northeastern Kentucky, Phalen (1912) divided the Pennsylvanian rocks into the Pottsville, Allegheny, Conemaugh, and Monongahela Formations. Ashley and Glenn (1906) subdivided the thick sequence of Breathitt rocks of the Cumberland overthrust block and named the Hance, Mingo, Catron, Hignite, and Bryson Formations, selecting certain coal beds as formational boundaries.

Extensive stratigraphic analyses and syntheses of the Pennsylvanian rocks of eastern Kentucky have been made by Wanless (1939, 1946, and 1975a) as a part of his studies of the Appalachian basin. Huddle and others (1963), aided by many earlier reports of the Kentucky Geological Survey and the U.S. Geological Survey, made detailed stratigraphic analyses of each coal district in eastern Kentucky and computed its coal reserves.

The earliest geological work in the western Kentucky coal field was carried out by Owen from early 1854 to 1859. He named the Caseyville Formation and the principal limestone beds of the overlying "Coal Measures," and established the system of numbering coal beds that has been only slightly modified by subsequent work. Significant stratigraphic contributions were made by Glenn (1912a and b, and 1922), who named the Tradewater, Lisman, and Dixon Formations, and extended the Carbondale Formation from Illinois into Kentucky. Kehn (1973) combined the Lisman and Henshaw Formations to form the Sturgis Formation. Other important contributions include reports by Hutchinson (1912) and Lee (1916), who were first to map and describe in detail the stratigraphy of the Pennsylvanian of western Kentucky, and Smith and Smith (1967), who were first to describe in detail the upper part of the Pennsylvanian section. Wanless (1975b) summarized the stratigraphy of the Western Coal Field as a part of his investigation of the Pennsylvanian of the Eastern Interior basin (Illinois basin).

In 1960, the U.S. Geological Survey and the Kentucky Geological Survey began a cooperative geological mapping program, and by 1977, all Kentucky had been mapped geologically at a scale of 1:24,000; these maps are published in the GQ (Geologic Quadrangle) Map Series of the U.S. Geological Survey. During this period, many refinements were made in Carboniferous lithostratigraphy (Englund and Windolph, 1971; Kepferle, 1971; Kepferle and Lewis, 1974; Lewis, 1971; Outerbridge, 1976; Sable and others, 1966; Weir and others, 1966); resource investigations by the Kentucky Geological Survey involving oil and gas, coal, limestone, and clay were accelerated, along with associated stratigraphic studies, and have resulted in many publications by the State Survey. Investigators using the geologic maps have published other research reports on details of the stratigraphy and sedimentation of the Mississippian (Kepferle, 1977; Weir, 1970; Indiana University, 1969, 1972; Vincent, 1975) and of the Pennsylvanian (Englund, 1964; Kehn, 1973; Kosanke, 1973). The most recent summary of Carboniferous rocks of the Eastern Interior basin (Pryor and Sable, 1974) covers parts of Kentucky and cites principal modern references. Stratigraphic information collected during the cooperative mapping program was used in compiling the present report.

MISSISSIPPIAN SYSTEM

Mississippian rocks in Kentucky are principally marine; environments of deposition ranged from relatively deepwater basin through shallow subtidal and supratidal to lower delta plain. Dominant lithologies, relative thicknesses, and relationships of Mississippian units are shown in figure 3. Nomenclature and unit correlations currently used in Kentucky are basically lithostratigraphic (figs. 4 and 5). Some biostratigraphic zones virtually correspond with lithostratigraphic units and serve as practical aids in field identification and mapping (fig. 6).

GEOLOGIC SETTING

Basal Mississippian rocks throughout Kentucky conformably overlie rocks of Late Devonian age, which are principally dark carbonaceous shale (Chattanooga, New Albany, and Ohio Shales) (fig. 4). The top of the Chattanooga and New Albany is the top of the Devonian succession in western, southern, and west-central Kentucky. Carbonaceous shale of Mississippian age, correlative with the Sunbury Shale, is present in uppermost New Albany beds of east-central Kentucky and the upper Chattanooga of southeastern Kentucky. In the parts of northeastern and southeastern Kentucky where the Bedford Shale and Berea Sandstone are present between the Ohio (or Chattanooga) and Sunbury Shales, the systemic boundary is within the Bedford Shale.

Mississippian strata in much of Kentucky are overlain by Pennsylvanian (Morrow) rocks. The systemic boundary generally is a disconformity, but strata that show continuous deposition extending from Late Mississippian into Early Pennsylvanian time are locally preserved in southeastern Kentucky. In extreme western Kentucky, Cretaceous sediments of the Mississippi Embayment unconformably overlie Mississippian units (fig. 1).

The Appalachian and Eastern Interior basins presently are separated by the north-trending Cincinnati arch. (See fig. 15.) The exact nature of the arch during Carboniferous time is uncertain. It was a positive feature during Late Devonian time, but depositional patterns in the Borden Formation (Osage) show no evidence of a north-trending arch across central Kentucky in Early Mississippian time. The Appalachian and Eastern Interior basins apparently were connected across southern Kentucky throughout Mississippian time, but the arch may have been a shoal or emergent lowland in northern Kentucky during the Late Mississippian. Tectonic activity during the Carboniferous is suggested by distinct thickness variations in Upper Mississippian units along the trends of the Kentucky River fault system and Waverly arch in northeastern Kentucky (Dever and others, 1977) and, conjecturally, along the trend of the Rough Creek fault system in western Kentucky (Craig and Connor, 1978) (see fig. 15).

STRATIGRAPHY

The Mississippian succession in Kentucky consists of four major lithogenetic groupings:

1. Distal terrigenous detrital deposits (shale, siltstone, and sandstone) of westward and southward prograding deltaic systems (Kinderhook, Osage): Bedford Shale, Berea Sandstone, Sunbury Shale, and Borden Formation below the Floyds Knob Bed.
2. Marine carbonate deposits, partly basinal but dominantly shallow-water shelf limestone and dolomite (Osage, Meramec): Fort Payne Formation, Muldraugh and Renfro Members of Borden Formation; Warsaw, Harrodsburg, Salem, St. Louis, and Ste. Genevieve Limestones.
3. Rhythmically alternating marine carbonate and terrigenous detrital deposits, shallow-water shelf limestone alternating with sandstone and shale from a southward and southwestward

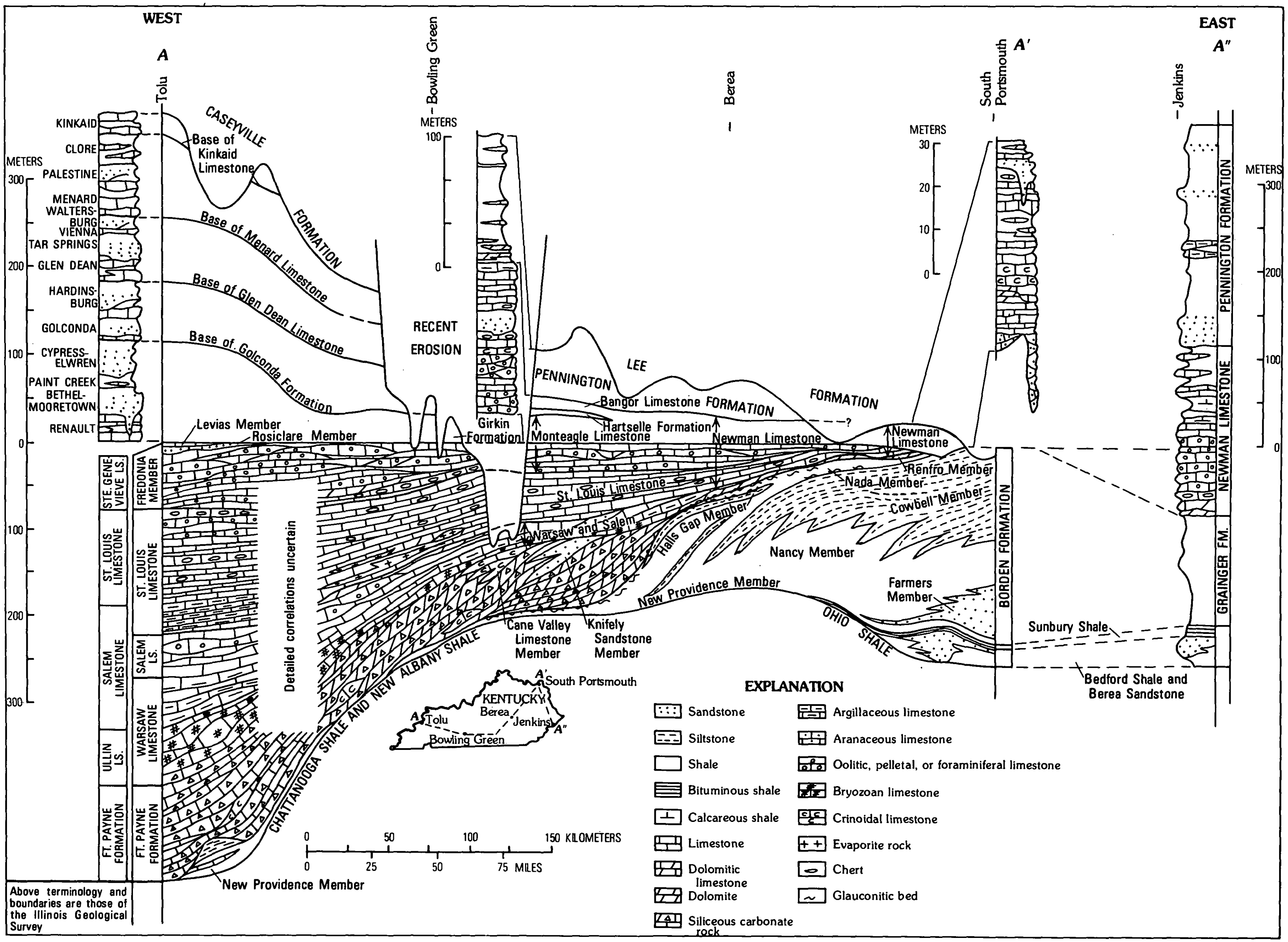

Figure 3.—Cross section showing Mississippian rock units and relationships in Kentucky. (All scales approximate.)

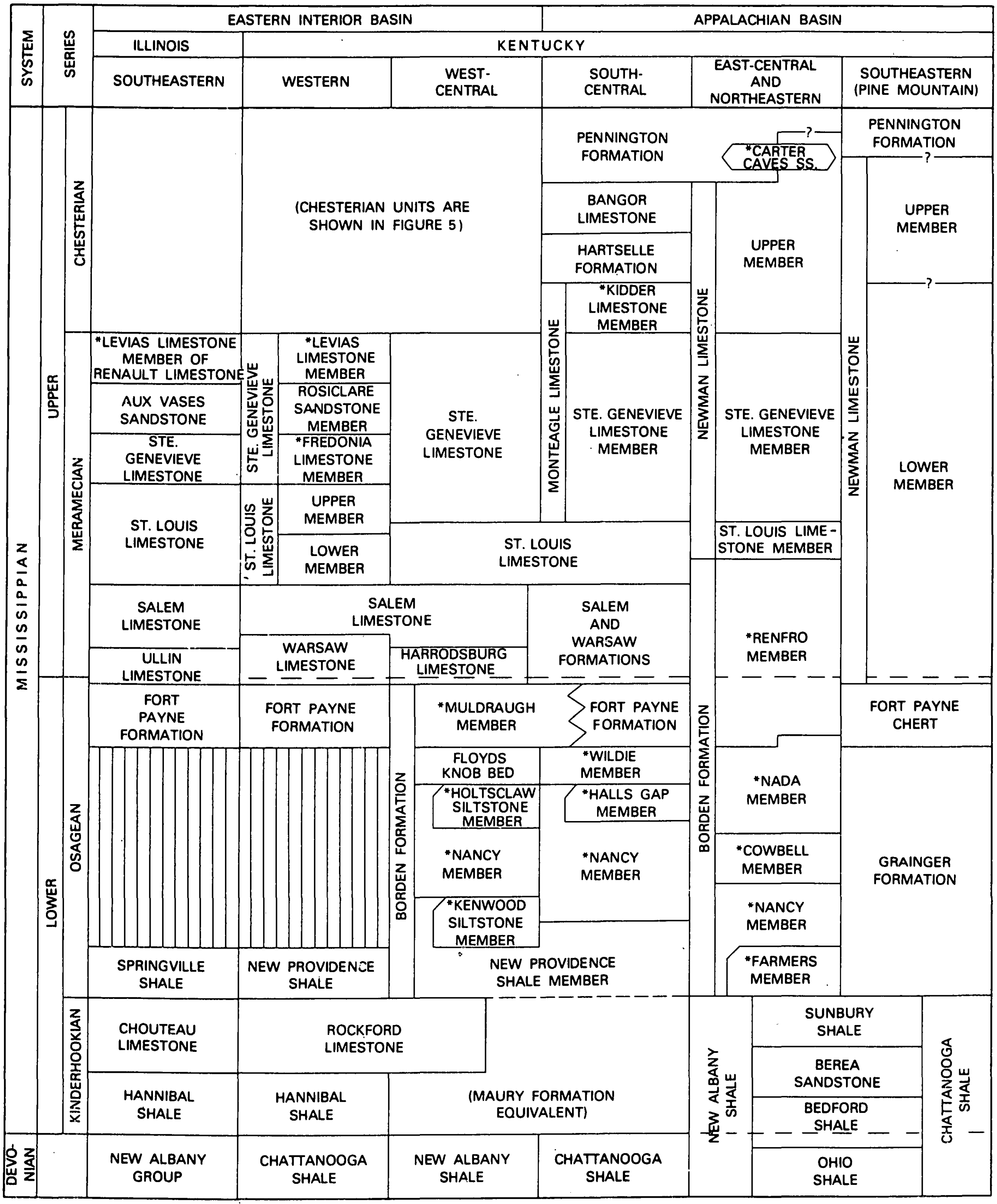

FIGURE 4.—Stratigraphic nomenclature of the Mississippian System in Kentucky and southeastern Illinois. Asterisk (*) indicates type section in Kentucky.

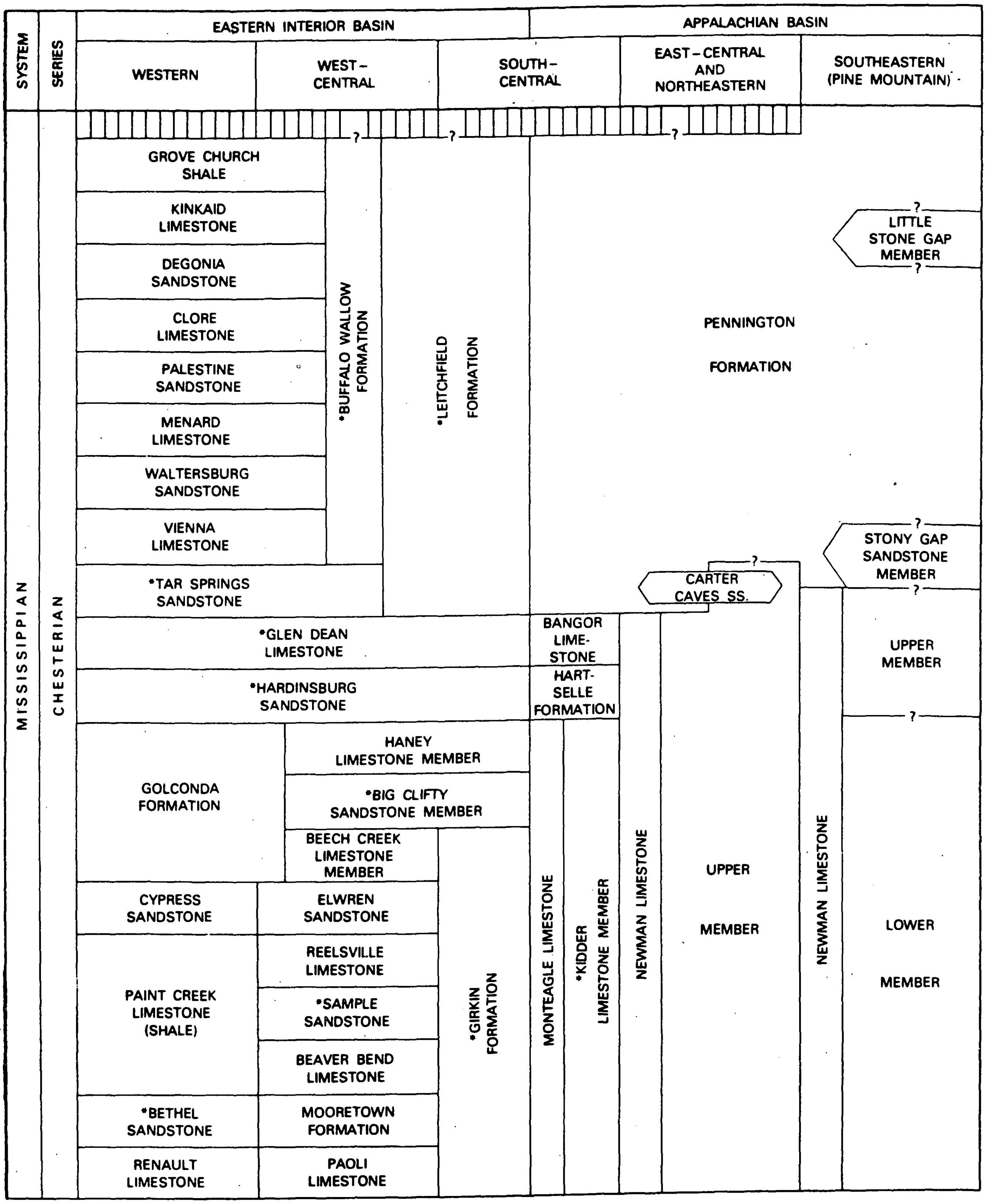

FIGURE 5.—Stratigraphic nomenclature of the Chester Series and equivalent strata in Kentucky. Asterisk (*) indicates type section in Kentucky.

prograding delta (Chester): Paoli-Renault Limestone through Grove Church Shale of western Kentucky; Paoli Limestone through Glen Dean Limestone correlatives in the Newman Limestone, Monteagle Limestone, Hartselle Formation and Bangor Limestone of south-central and eastern Kentucky.

4. Terrigenous detrital deposits (dominantly shale, varied amounts of sandstone, some marine limestone and dolomite) of westward and southward prograding deltaic systems (Chester): Pennington Formation of eastern Kentucky; Buffalo Wallow and Leitchfield Formations of western Kentucky.

Major source areas for Mississippian terrigenous sediments were (1) to the northeast, within or beyond the Acadian tectonic belts of the Northeastern United States and eastern Canada, and, possibly, northern Canada; and (2) to the east, within or beyond the Piedmont province of the Eastern United States. A third possible source for Upper Mississippian sediments has been reported to the south in the area between the Ouachita Mountains of Arkansas and the Black Warrior basin of Alabama and Mississippi (Thomas, 1974).

During Kinderhook time, distal deltaic deposits (Bedford Shale, Berea Sandstone) prograded southward and westward into eastern Kentucky, spreading across Late Devonian carbonaceous sediments (Ohio and Chattanooga Shales) (Pepper and others, 1954). When progradation ceased, the deltaic deposits were onlapped eastward and northeastward by carbonaceous sediments of Mississippian age (Sunbury Shale). Thin distal deposits of shale and limestone (Hannibal Shale, Rockford Limestone) probably from northern sources are preserved in western Kentucky, but across much of the State, the Kinderhook is locally represented only by a very thin stratum of clay shale and phosphatic nodules, suggesting starved-basin conditions.

Osage time was marked by a major renewal in westward and southwestward deltaic progradation into Kentucky. The lower and middle Borden Formation is a sequence that coarsens progressive from deepwater, prodelta clay shale (New Providence Shale Member) upward through silty shale (Nancy Member) into siltstone (Holtsclaw Siltstone, Halls Gap, and Cowbell Members) containing local delta-front turbidite deposits (Kenwood Siltstone, Farmers, and Wildie Members) (Kepferle, 1977; Moore and Clarke, 1970; Peterson and Kepferle, 1970; Weir, 1970). The western limit of foreset siltstone forms a remarkably straight, northwestward-trending Borden delta front, extending across west-central and south-central Kentucky. Water depths seaward of the front may have been as great as 85 m (Indiana University, 1972). A depositional hiatus following active progradation is indicated by the presence of a thin glauconitic unit (Floyds Knob Bed, Floyds Knob correlative in Wilde and Nada Members) extending across the outer delta platform and slope and into the basin.

Extensive carbonate deposition began during Osage time, partly contemporaneous with but mostly following the deltaic progradation, and continued through Meramec into Chester time. The initial deposits were argillaceous and siliceous, dolomitic siltstone, silty dolomite, and micrograined and crinoidal limestone (Fort Payne Formation, Muldraugh and lower Renfro Members of the Borden Formation), which were deposited seaward (west) of the delta front and across the prodelta slope and outer delta platform in basinal to supratidal environments. Locally, distinct elongate bodies of limestone and sandstone (Cane Valley Limestone and Knifley Sandstone Members of the Fort Payne Formation) were formed as submarine barrier-shoals and banks parallel to and seaward of the delta front (Indiana University, 1972). Succeeding bryozoan-crinoidal limestone (Harrodsburg and Warsaw Limestones) and bioclastic, pelletal, and foraminiferal limestones (Salem Limestone) form widespread units in western and south-central Kentucky, but pinch out northeastward across east-central Kentucky. These units contain varied amounts of dolomitic limestone, shale, and sandstone. The Warsaw in western Kentucky has a variable thickness reflecting deposition on the irregular basinal deposits of the Fort Payne. The first major cycle of carbonate deposition during this period is capped by a sequence of tidal-flat and supratidal dolomite and limestone containing evaporite deposits (lower St. Louis Limestone, upper Renfro Member of the Borden Formation).

During renewed transgression in late Meramec time, the initial deposits were subtidal, fossiliferous, micrograined, and bioclastic limestone (upper St. Louis Limestone), succeeded by shallow subtidal oolitic and bioclastic limestone (Ste. Genevieve Limestone). In western Kentucky, subsidence virtually in equilibrium with basin filling probably began in St. Louis time or somewhat earlier and continued through the remainder of the Mississippian Period. Carbonate deposition was interrupted at the end of Meramec time by a period of widespread exposure. A prominent zone of altered limestone

(Bryantsville Breccia Bed) formed during subaerial exposure and vadose diagenesis at the top of the Ste. Geneieve throughout much of its outcrop belt across the State. Episodes of renewed activity along the early Paleozoic Waverly arch and Kentucky River fault system interrupted St. Louis and Ste. Genevieve deposition in northeastern Kentucky and were followed by a period of extensive erosion on the upthrown (northern) side of the fault system.

During Chester time, about 370 m of rhythmically alternating carbonate and terrigenous detrital units accumulated in western Kentucky in very shallow water. Carbonate sediments were deposited on a broad shallow marine shelf; terrigenous sand and clay were brought in by prograding deltaic lobes of the Michigan River, which intermittently encroached southward into the shallow shelf environment (Potter, 1963; Swann, 1963, 1964). Elongate sandstone bodies were probably mainly of distributary origin, containing one or more tidal-channel deposits (Mooretown-Bethel); widespread shale was delta platform clay and prodelta clay. Thin coal was formed locally. Lateral shifting of the Michigan River system across central Illinois and Indiana was a controlling factor that determined gross variations in detrital sediment distribution in Kentucky; periodic climatic or tectonic oscillations in source areas controlled the volume of detrital input into the Eastern Interior basin. The Cincinnati and Ozark arch areas were relatively positive features, possibly shoals or emergent lowlands, which partly controlled the axis of detrital deposition (Swann, 1963, p. 15). Major shoreline fluctuations, combined with diminished detrital supply, contributed to widespread carbonate deposition between times of maximum detrital deposition. The proportion of shale and sandstone to limestone generally increases northward across western Kentucky and upward within the Chester succession.

In southern and eastern Kentucky, lower and middle Chester units and their correlatives are dominantly limestone; detrital units that are relatively thick and extensive in western Kentucky commonly are represented only by thin deposits of shale. Sandstone (Hartselle Formation) possibly derived from a southern source area, extends into south-central Kentucky from Tennessee and may have been deposited as a barrier island or an offshore bar (Thomas, 1974). Limestone of lower Chester age contains several zones of alteration that were formed in part during prolonged exposure and diagenesis of tidal-flat and supratidal deposits capping a series of fining-upward sequences. In northeastern Kentucky, the distribution of lower Chester correlatives reflects deposition on the post-Ste. Genevieve erosional surface and the persistence of the Waverly arch (see structure map, fig. 15) as a positive feature. In southeastern Kentucky, the Meramec and lower through middle(?) Chester correlatives exposed along Pine Mountain consist of very thick deposits of shelf limestone and thin shale. These deposits indicate that shallow marine carbonate deposition kept pace with the relatively rapid subsidence of this part of the Appalachian basin.

During latest Chester time, terrigenous detrital deposits (Pennington Formation; upper Newman Limestone (Englund and Windolph, 1971)) of westward-prograding deltaic systems spread across eastern Kentucky. The change from carbonate deposition to deltaic detrital deposition was gradual; the upper part of the carbonate succession contains increased amounts of interbedded shale and argillaceous limestone. The Pennington is dominantly shale containing varied amounts of sandstone, some limestone and dolomite, and minor coal, representing offshore-bar, lagoonal, tidal-flat, estuarine, distributary, and coastal-marsh deposits. Southeastward, sandstone becomes a major constituent of the Pennington. A linear sandstone body (Carter Caves Sandstone) in northeastern Kentucky is described variously as an offshore bar (Englund and Windolph, 1971), a beach-barrier island system (Horne and others, 1974), or a tidal-channel deposit paralleling the Waverly arch (Ettensohn, 1977, p. 18–29).

In west-central Kentucky, the upper part of the Chester succession (Buffalo Wallow and Leitchfield Formations) in the eastern part of the Eastern Interior basin is lithologically similar to the Pennington of eastern Kentucky. The geographic proximity and lithologic similarity of these approximately correlative units suggest that the Buffalo Wallow and Leitchfield may contain detrital rocks derived from both the southward-prograding Michigan River and westward-prograding Pennington deltaic systems.

BIOSTRATIGRAPHY

Taxonomy and zonation of megafossils in Mississippian rocks stem from extensive early studies in Kentucky and adjacent States by Stuart Weller (1920, 1926), J. M. Weller (1931), Butts (1915, 1917, 1922), and Ulrich (1917), and others. These studies were reviewed and updated by Weller and Sutton 1940). Crinoids, brachiopods, blastoids, bryozoans, solitary and colonial corals, and echinoids are dominant forms in the Mississippian assemblage; pelecypods, gastropods, and trilobites are locally abundant. Crinoid studies by Horowitz (1965), and biofacies studies of a Chester rock unit (Vincent, 1975) are two examples of the many selective studies done in recent years.

A significant change in the crinoid fauna marks the Chester-Meramec series boundary in western, west-central, and south-central Kentucky—the change from *Platycrinites penicillus* Meek and Worthen, a Meramec form, to *Talarocrinus* spp., a Chester form. The fauna change corresponds to the time of formation of a widespread zone of altered limestone (Bryantsville Breccia Bed) interpreted to have developed during subaerial exposure and diagenesis. Other Mississippian boundaries and the Devonian-Mississippian systemic boundary appear to occur within intervals of continuously deposited strata, and faunal criteria for specific boundary demarcation are not conclusive. However, many specific and generic forms have proved valuable aids in practical recognition and mapping of stratigraphic units. Figure 6 shows general stratigraphic occurrences of selected fossil faunal elements that have been successfully used in mapping Mississippian rock units in Kentucky. The list is incomplete and does not show faunal ranges.

Microfossils in Mississippian rocks of Kentucky include endothyrid and paleotextulariid Foraminifera, conodonts, and ostracodes. Although no systematic studies have been done for the entire system in Kentucky, foraminiferal studies include those by Browne and Pohl (1973), Browne and others (1977), Conkin (1954, 1956, 1961), Pohl and others (1968), and Pohl (1970). Conodont studies, following zonation used in the Mississippi Valley (Collinson and others, 1962, 1971), include those by Rexroad (1958, 1969), Nicoll and Rexroad (1975), Rexroad and Liebe (1962), and Howoritz and Rexroad (1972).

The zonation of plant megafossils in western Kentucky and adjacent States of the Eastern Interior basin has established criteria for distinguishing Mississippian sandstone from lithologically similar Pennsylvanian strata (Jennings, 1977). A rare lycopod occurrence in the basal St. Louis Limestone of west-central Kentucky was reported by Browne and Bryant (1970).

MISSISSIPPIAN-PENNSYLVANIAN BOUNDARY

The Mississippian-Pennsylvanian boundary along the margins of the Western Coal Field and northwest margin of the Cumberland Plateau has long been interpreted to represent a regional unconformity (Miller, 1919, p. 252). Extensive subsurface work by Bristol and Howard (1971) in western Kentucky helped to identify a general northward and northeastward truncation of progressively older Mississippian strata and several broad southwest-trending sub-Pennsylvanian valleys (fig. 7). These valleys or channels are incised as much as 75 m into the gently rolling plain of the truncated Mississippian surface and may locally represent removal of more than 275 m of Mississippian strata. Detailed studies of parts of these channels have been made by Davis and others (1974) and Shawe and Gildersleeve (1969). Extending eastward from the easternmost channel shown in figure 7 is a tongue of conglomeratic sandstone that has been interpreted by Burroughs (1923) as the remnants of a "Pottsville-filled channel" resting on rocks as old as the St. Louis Limestone (Mississippian).

In the narrow outcrop belt along the western edge of the Cumberland Plateau of eastern Kentucky, the unconformity is marked by channels as much as 60 m deep and locally by paleokarst topography developed on Mississippian limestone. The sub-Pennsylvanian surface (fig. 8) also shows a north or north-northwestward truncation of Mississippian strata, probably reflecting the influence of the Cincinnati and Waverly arches at that time (Englund, 1972).[1]

The existence of the Mississippian-Pennsylvanian unconformity in northeastern Kentucky was challenged by Horne and Ferm (1970), Horne and others (1971), Ferm and others (1972), Ferm (1974), and Horne and others (1974), who attempted to show the relationship of the largely terrestrial Pennsylvanian deposits (Lee and Breathitt Formations) above the unconformity to the underlying marine Mississippian strata by means of a depositional model. If correct, their thesis is highly significant in considering the age and stratigraphic relations of many Carboniferous units in the Appalachian and midcontinent area. Their depositional model, called the "Lee-Newman barrier shoreline model" (Horne and others, 1971), identifies orthoquartzite (commonly Lee Formation) as beach-barrier deposits that grade landward into lagoonal and lower delta-plain shale, subgraywacke, and coal (Breathitt Formation) and seaward into red and green marine shale (Pennington Formation and Nada Member of Borden Formation) that surrounds offshore carbonate islands (Newman Limestone).

[1]Strata in northeastern Kentucky identified as Pennington by various workers have been assigned to the Newman Limestone by Englund and Windolph (1971). The relations of these rocks, generally less than 10 m thick, to strata of the Pennington Formation in south-central Kentucky, as much as 50 m thick, or those in the type area of Cumberland Mountain, as much as 350 m thick, are uncertain.

SERIES	WESTERN		WEST-CENTRAL		SOUTH-CENTRAL AND EAST-CENTRAL	
CHESTERIAN	KINKAID, MENARD, AND CLORE LIMESTONES	*Spirifer increbescens* Hall *Composita subquadrata* (Hall) *Sulcatopinna missouriensis*	BUFFALO WALLOW AND LEITCHFIELD FORMATIONS	*Spirifer increbescens* Hall *Composita subquadrata* Hall	PENNINGTON FORMATION	*Pterotocrinus* spp.
CHESTERIAN	GLEN DEAN LIMESTONE	*Pterotocrinus* spp* *Archimedes* spp*	GLEN DEAN LIMESTONE	*Pterotocrinus* spp.* *Prismopora serrulata* Ulrich *Archimedes* spp.*	BANGOR LIMESTONE	*Archimedes* spp.*
CHESTERIAN	GOLCONDA FORMATION		BEECH CREEK AND HANEY LIMESTONES	*Archimedes* spp.* *Inflatia inflata* (McChesney)*	MONTEAGLE LIMESTONE (NEWMAN LIMESTONE)	Large crinoid stem segments* *Pentremites* spp.* *Agassizocrinus* spp.
CHESTERIAN	PAINT CREEK AND RENAULT LIMESTONES	*Talarocrinus* spp.	PAOLI, BEAVER BEND, AND REELSVILLE LIMESTONES	*Agassizocrinus* spp. *Lithodromus veryi* (Greene) *Talarocrinus* spp.	MONTEAGLE LIMESTONE (NEWMAN LIMESTONE)	*Talarocrinus* spp.
MERAMECIAN	STE. GENEVIEVE LIMESTONE	*Lithostrotion (Siphonodendron) genevievensis* *Platycrinites penicillus* Meek and Worthen		*Lithostrotion (Siphonodendron) genevievensis* *Platycrinites penicillus* Meek and Worthen	MONTEAGLE LIMESTONE (NEWMAN LIMESTONE)	*Platycrinites penicillus* Meek and Worthen
MERAMECIAN	ST. LOUIS LIMESTONE	*"Lithostrotion" proliferum* Hall* *Lithostrotion castelnavi* Hayasaka* *Melonechinus* sp. *Syringopora* sp.	ST. LOUIS LIMESTONE	*"Lithostrotion" proliferum* Hall* *Lithostrotion castelnavi* Hayasaka* *Melonechinus* sp. *Archeocidaris* sp. *Syringopora* sp.	ST. LOUIS LIMESTONE (NEWMAN LIMESTONE)	*"Lithostrotion" proliferum* Hall *Lithostrotion castelnavi* Hayasaka *Syringopora* sp.
MERAMECIAN	SALEM LIMESTONE	*Endothyra baileyi* Hall *Hapsiphyllum* sp. *Brachythyris subcardiiformis* (Hall)	SALEM LIMESTONE	*Endothyra baileyi* Hall *Brachythyris subcardiiformis* (Hall) *Hapsiphyllum* sp.	SALEM AND WARSAW LIMESTONES	*Hapsiphyllum* sp.
MERAMECIAN —?—	WARSAW LIMESTONE	*Echinocrinus* sp.* *Spirifer lateralis* *Pentremites conoideus* *Talarocrinus* sp.	HARRODSBURG LIMESTONE	*Marginirugus magnus*	SALEM AND WARSAW LIMESTONES —?—	*Spirifer lateralis*
OSAGEAN	FORT PAYNE FORMATION		BORDEN FORMATION	*Orthotetes keokuk* (Hall) *Syringothyris textus* (Hall) Very large crinoid stem segments*	FORT PAYNE FORMATION	Very large crinoid stem segments*

FIGURE 6.—Stratigraphic occurrence of selected Mississippian fossil fauna, on the basis of general abundance and ease of recognition, that are helpful in recognition of map units in Kentucky. Asterisk denotes very abundant; shaded areas denote intervals of largely terrigenous detrital strata.

They interpreted the intra- and post-Mississippian erosional unconformities, described by previous workers, to be depositional or facies-controlled boundaries.

Central to the development of the Lee-Newman model is a cross section of Carboniferous rocks ex-

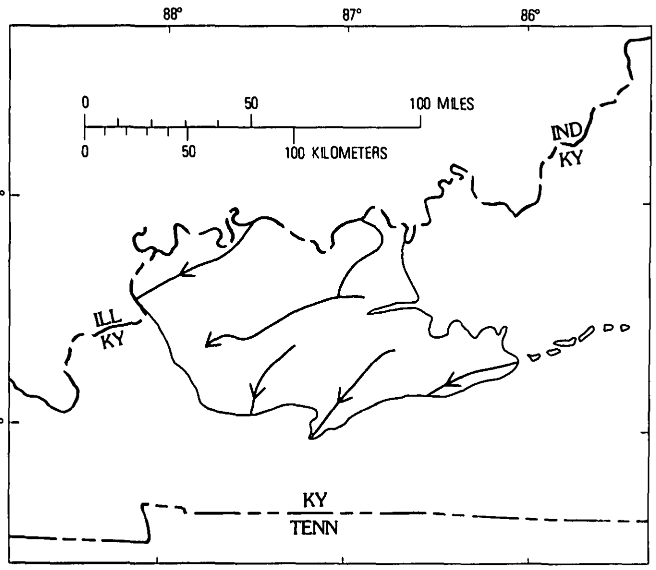

FIGURE 7.—Sub-Pennsylvanian valley systems in the western Kentucky coal field.

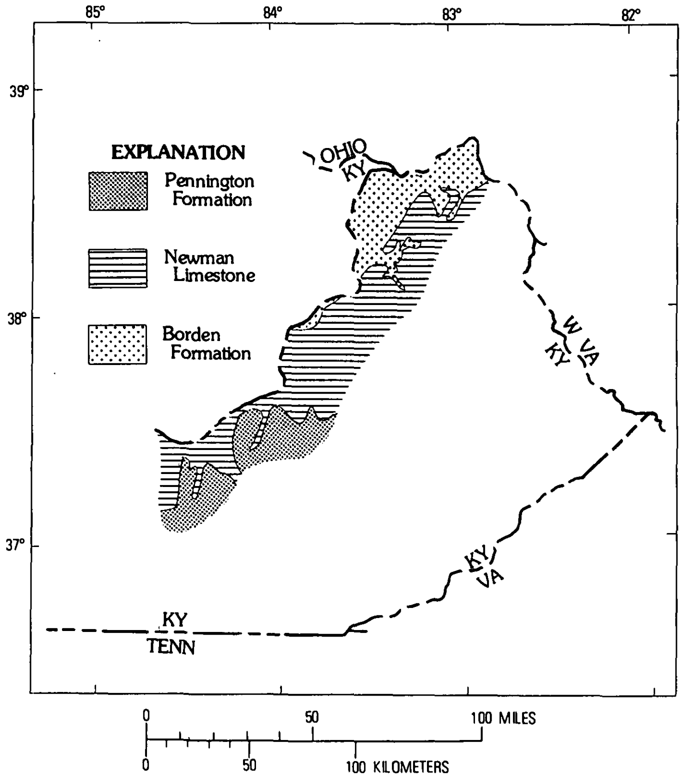

FIGURE 8.—Generalized geologic map of the pre-Pennsylvanian surface in the northwest part of the Cumberland Plateau, eastern Kentucky.

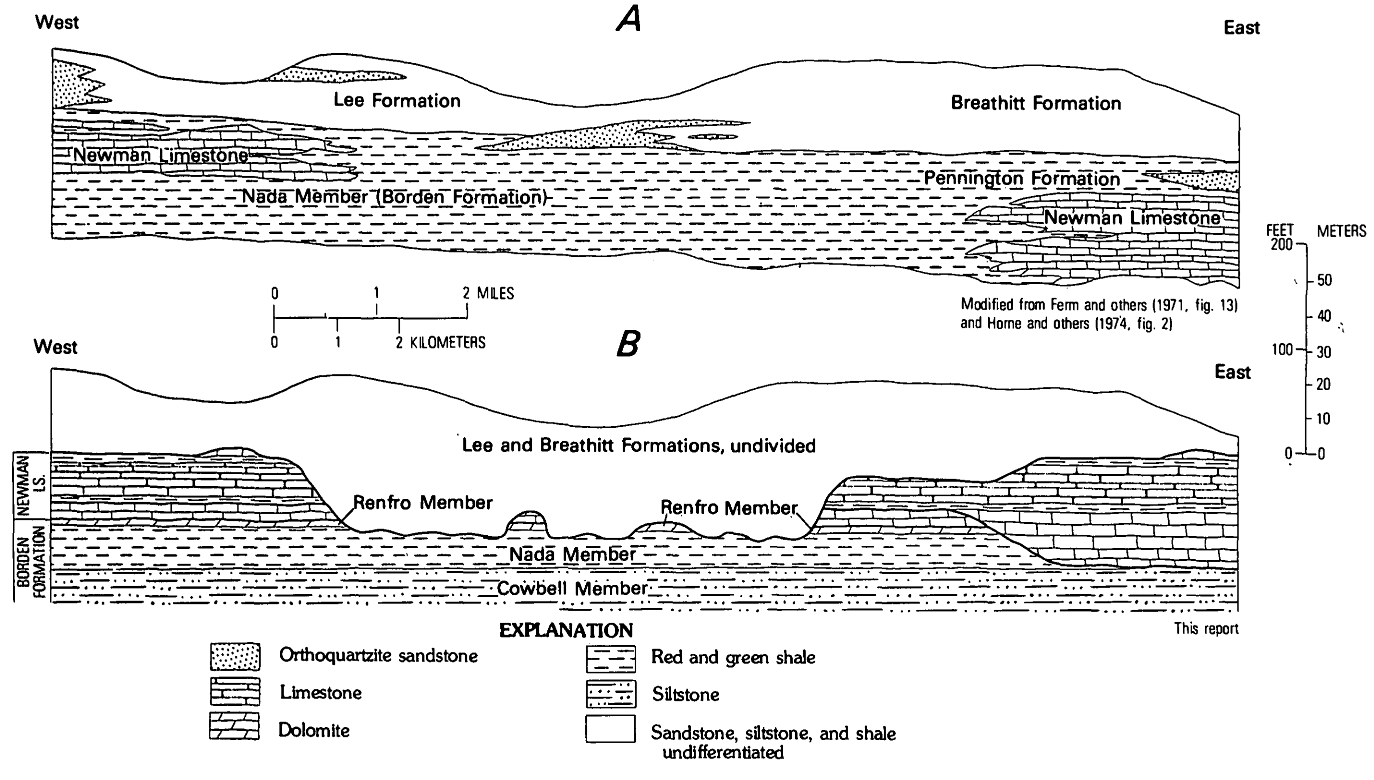

FIGURE 9.—Generalized cross sections showing two interpretations of Carboniferous rocks exposed along Interstate Highway 64, eastern Rowan and western Carter Counties, northeastern Kentucky.

posed along Interstate Highway 64 in northeastern Kentucky. Relations between rock units along part of the highway as interpreted by Ferm and others (1971, fig. 13) and Horne and others (1974, fig. 2) are shown in fig. 9A. The intertonguing of a thick sequence of marine shale (Pennington and Nada) with two isolated bodies of carbonate rocks (Newman) and lenses of orthoquartzite (Lee) is intended to show a west-migrating shoreline environment.

The proposed depositional model is untenable in view of field relationships between lithologic units in the area. Study of exposures along the interstate highway by the present writers has established the presence of erosional remnants and lithologic sequences that indicate the former continuity of carbonate units across the area (fig. 9B). No intertonguing of limestone and shale along the margins of the carbonate bodies was seen. Red and green shales in the road section were found to belong to the Nada Member of the Borden Formation and two thin shale units in the Newman Limestone; the measured thicknesses of these shales are less than half that indicated in figure 9A. In the authors' opinion, the distribution of rock units shown in figure 9B reflects erosional and depositional thinning related to two regional unconformities that have been described by Dever and others (1977), Patterson and Hosterman (1962), and Sheppard (1964). The lower unconformity followed deposition of the basal limestone unit of the Newman and locally cuts into the Cowbell Member of the Borden Formation. The upper unconformity is Mississippian-Pennsylvanian; it is overlain by deltaic carbonaceous shale and siltstone containing minor sandstone bodies that are dominantly fluviatile in origin. The unconformity has a local relief of about 25 m; total thickness of missing Mississippian strata may be more than 50 m.

In southeastern Kentucky, the Mississippi-Pennsylvanian systemic boundary occurs in the upper part of the Pennington Formation in an intertonguing and intergrading sequence of siltstone, sandstone, and shale: strata above are largely continental, and those below are largely marine. Englund (1974, p. 38) identified a major Pennsylvanian unconformity at the base of the New River Formation in Virginia and West Virginia and at the base of the Middlesboro Member of the Lee Formation in southeastern Kentucky. (See fig. 12.) He showed that this unconformity cuts progressively older strata northwestward and suggested that it coincides with the widespread Mississippian-Pennsylvanian unconformity of the midcontinent region.

PENNSYLVANIAN STRATA OF EASTERN KENTUCKY

The Pennsylvanian rocks of eastern Kentucky form a clastic wedge that thickens southeastward toward the axis of the Appalachian basin. The rocks crop out in an area of about 27,000 km^2 and occupy a central part of the Appalachian coal field that extends from New York to Alabama.

The depositional character of the Pennsylvanian strata is deltaic. The lower part generally is dominated by thick orthoquartzite and the upper part by siltstone, shale, and generally thin discontinuous subgraywacke. Although only a few widespread marine transgressions took place during Pennsylvanian time, many coal beds are overlain by shale that locally contains sparse brackish-water or marine fauna.

GEOLOGIC SETTING

By Late Mississippian time, eastern Kentucky was the site of shallow-water clastic deposition, which, except where interrupted by the formation of swamps, continued throughout Pennsylvanian time. In southeastern Kentucky, or the central part of the basin, continuous deposition took place across the systemic boundary, while to the northwest, basal Pennsylvanian sediments were disconformably deposited on the eroded Mississippian surface.

Pennsylvanian deposition was strongly influenced by the rapidly subsiding Appalachian trough, whose axis was southeast of and generally parallel to the strike of Pine and Cumberland Mountains. The cross section in figure 10 shows the great thickening of sedimentary rocks toward the axis of the trough. Figure 11 illustrates the influence of the subsiding trough on deposition of part of the Breathitt Formation. Campbell (1898) thought that much of the northwestward thinning of Early Pennsylvanian strata was due to onlap and that as much as one-quarter of the basal Lee section is not present in outcrops of the Pottsville escarpment along the western border of the basin.

Most Upper Pennsylvanian rocks have been eroded from eastern Kentucky, except for those preserved in a broad syncline in northeastern Kentucky. (See fig. 15.) Although the section locally may be thick enough to include Permian strata, such have not been identified.

STRATIGRAPHY

The Pennsylvanian strata of eastern Kentucky comprise locally part of the Pennington Formation

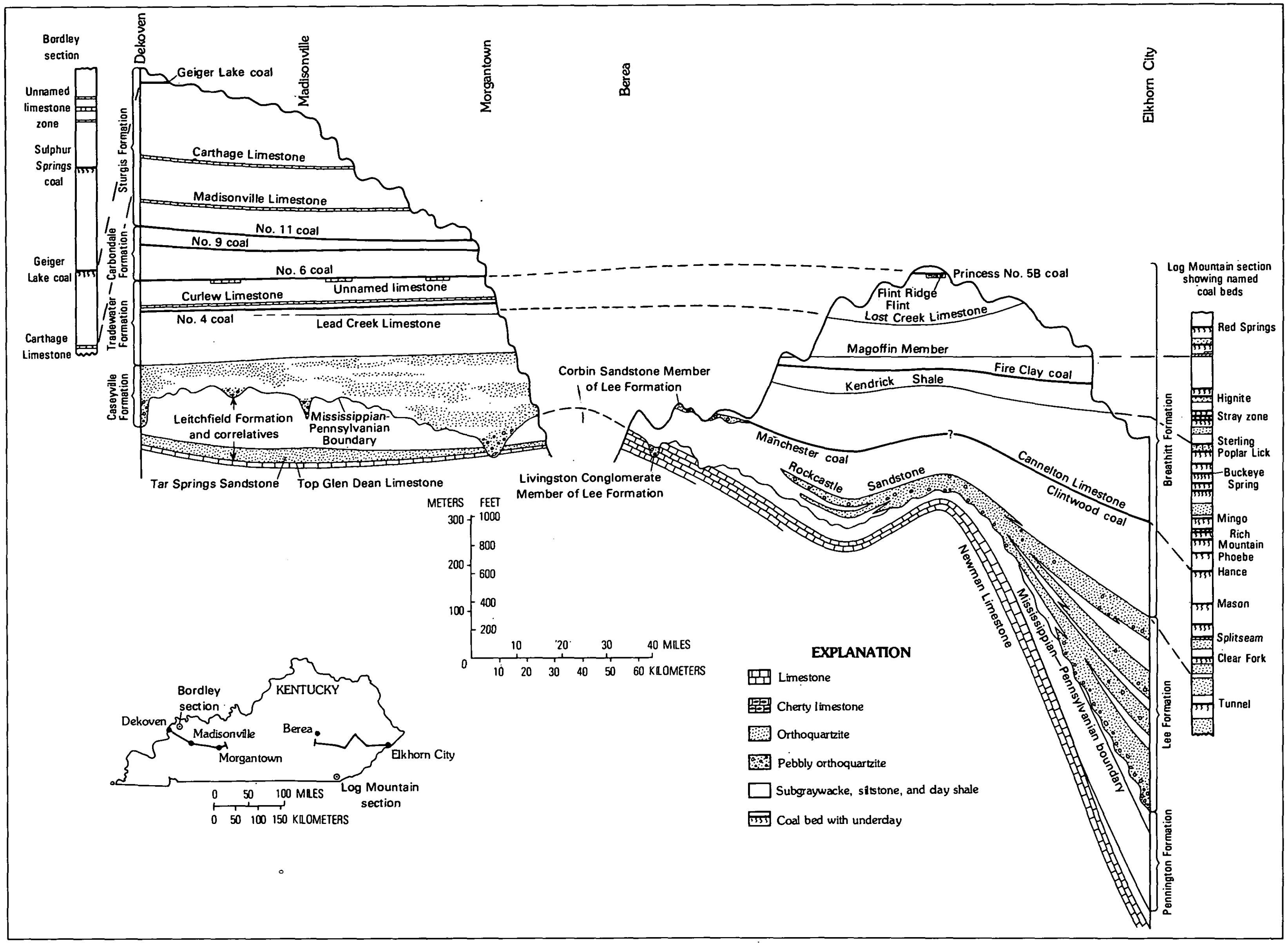

FIGURE 10.—Generalized cross sections of the Pennsylvanian of eastern and western Kentucky. Missing section above land surface across Cincinnati arch represents a gap of about 200 km. Anticlinal structure in eastern Kentucky cross section is only apparent and is due to placement of section line. Sandstone of the Log Mountain section is subgraywacke except that of the Lee Formation.

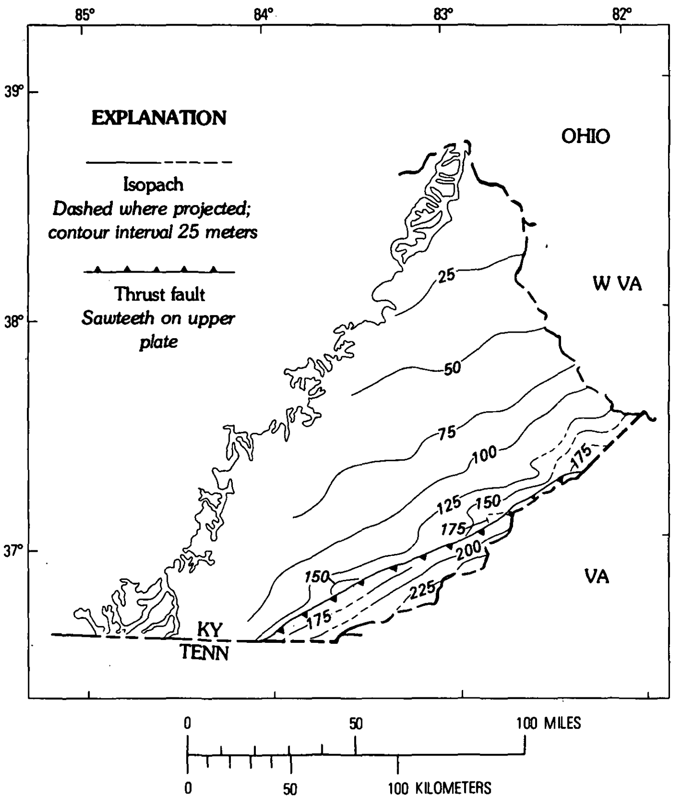

FIGURE 11.—Isopach map showing interval between the base of the Kendrick Shale of Jillson (1919) and the base of the Magoffin Member of the Breathitt Formation in eastern Kentucky.

and all the overlying Lee, Breathitt, Conemaugh, and Monongahela Formations.

PENNINGTON FORMATION

The upper part of the Pennington Formation in southeastern Kentucky contains Pennsylvanian flora (Maughan, 1976). The Mississippian-Pennsylvanian systemic boundary there occurs in a gradational sequence between the highest marine unit (Little Stone Gap Member of the Pennington Formation of Mississippian age) and the base of the Middlesboro Member of the Lee Formation. This sequence includes reddish-, greenish- and dark-gray clay shale, gray and brownish-gray siltstone, coarse- to fine-grained pebbly orthoquartzite, and fine-grained silty sandstone. Thin coal beds and underclay that occur near the top of the Pennington are truncated locally by the Middlesboro Member of the Lee Formation in southeastern Kentucky.

LEE FORMATION

The Lee Formation is characterized by massive pebbly orthoquartzite that locally contains lenses of conglomerate; in places, sandstone makes up more than 80 percent of the formation. In extreme southeastern Kentucky, the unit is locally more than 500 m thick and has been divided into eight members, six of which, the Pinnacle Overlook, Chadwell, White Rocks, Middlesboro, Bee Rock Sandstone, and Naese Sandstone Members, are dominantly sandstone (Englund, 1964). The other two, the Dark Ridge and Hensly Members, consist generally of carbonaceous siltstone and shale, thin bedded subgraywacke, and coal. Figure 12 shows the relations of these units in various parts of the Cumberland overthrust block.

Along the Pottsville escarpment, only the extensively mapped and named pebbly orthoquartzite units are assigned to the Lee Formation: the Livingston Conglomerate, Rockcastle Sandstone, Corbin Sandstone, and Grayson Sandstone Members. Other quartzose sandstones occur between these named members, but they are generally thin and discontinuous, and all pinch out into or locally intergrade with siltstone or subgraywacke of the Breathitt Formation.

The Lee Formation is composed of a series of broad orthoquartzite lobes generally oriented northeast, generally parallel with the axis of the Appalachian basin and showing a dominant southwest transport direction (Potter and Siever, 1956 a and b; Englund and Delaney, 1966; Englund, 1974). The orthoquartzite lobes of the Cumberland overthrust block intertongue with or grade into nonresistant subgraywacke to the southeast in southwestern Virginia, and siltstone and subgraywacke to the northwest (Englund, 1968, pl. 5). The thickest part of each successive sandstone member is farther northwest, and in places it cuts into the older sandstone member. Thus, the top of the Lee Formation is placed at stratigraphically higher levels toward the northwest as shown in figure 13.

Ferm (1974, p. 94) and Donaldson (1974, p. 48) suggested that the Lee Formation of eastern Kentucky is a beach-barrier and back-barrier complex of northwestward-migrating shoreline environments. They suggested that the dominant southwest current direction of these strata was caused by longshore currents and southwestward migration of tidal channels. However, the marine rocks that should be associated with a beach or barrier system, are rare in the Lee Formation or intercalated Breathitt strata. On the contrary, the Rockcastle and Corbin Sandstone Members pinch out into deltaic siltstone and sandstone. Pennsylvanian strata underlying the Rockcastle and Corbin consist dominantly of car-

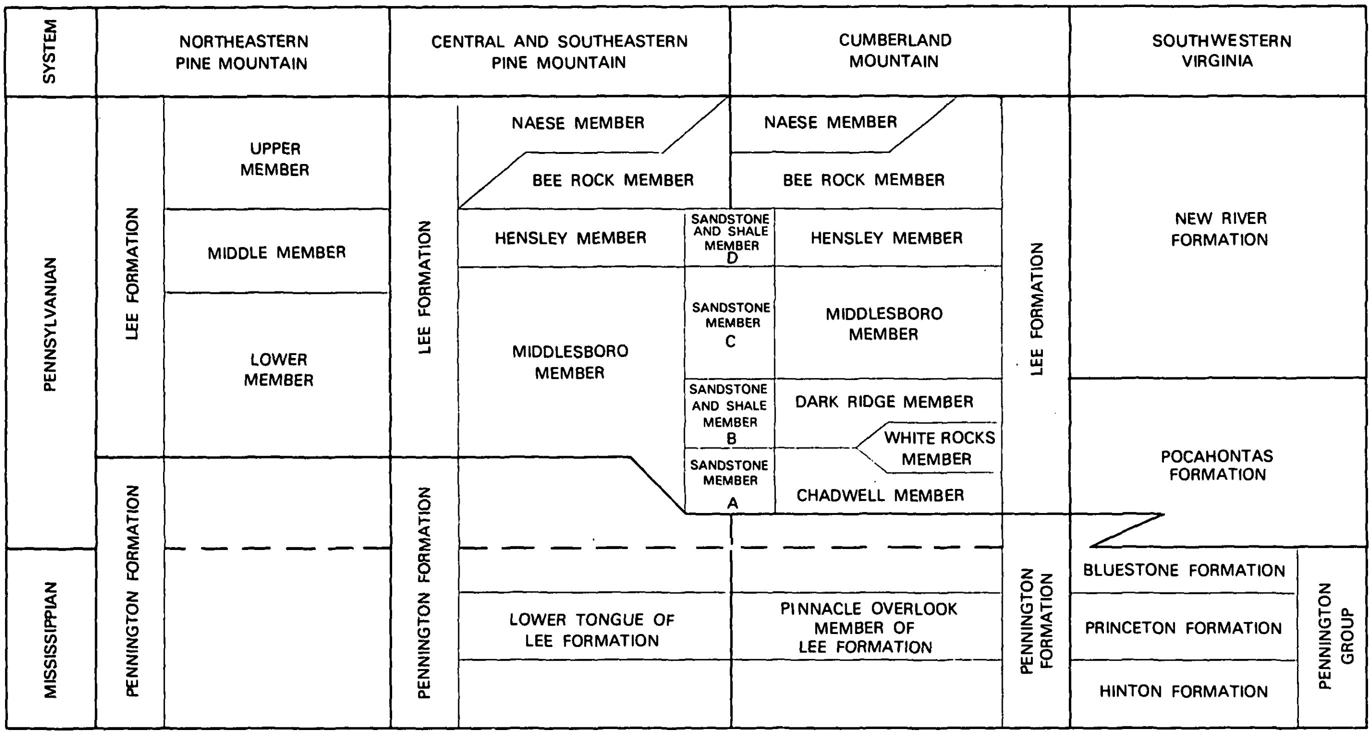

FIGURE 12.—Correlation chart of the Lee Formation in southeastern Kentucky and southwestern Virginia.

bonaceous shale and siltstone that contain plant material and coal beds, and seat rocks that contain abundant root impressions. Some of these basal strata consist of coarsening upward sequences that range from 1 m to as much as 10 m in thickness. Evidence of bioturbation is common, but few brackish-water or marine fauna are present. The sequences do not persist laterally more than a few kilometers and probably were deposited in small shallow interdistributary bays associated with lower delta-plain deposits. The lithology and interrelations of the lower part of the exposed Pennsylvanian section suggest that the sandstone members of the Lee Formation were large sand-filled distributary channels of a dominantly southwest-prograding delta.

BREATHITT FORMATION

The Breathitt Formation crops out over most of the eastern coal field.[2] The Breathitt has been locally ranked as a group and has been divided into formations on the basis of key beds, but as these formations are all lithologically alike, they are not differentiated in the following discussion. Regionally, the Breathitt and generally underlying Lee Formation intertongue. In most areas, the base of the Breathitt is placed at the top of the uppermost cliff-forming orthoquartzite, but along the Pottsville escarpment all Pennsylvanian strata except for the named members of the Lee Formation having regional extent are assigned to the Breathitt Formation (Weir and Mumma, 1973).

The Breathitt Formation is as much as 950 m thick in southeastern Kentucky but is preserved in its entirety only in northeastern Kentucky, where it is about 250 m thick. The formation is characterized not only by large differences in thickness but also by rapid lateral changes in lithology. These characteristics have made basin-wide correlations difficult, particularly in the lower part of the section. The formation contains most of the minable coal in eastern Kentucky. Coal occurs in as many as 30 major coal beds or coal zones to which more than 150 names have been applied; some of the most widely used names are included in figure 13.

The formation consists of siltstone and clay shale, subgraywacke, coal, ironstone, and limestone. Siltstone and clay shale intergrade, are commonly car-

[2] The name "Pottsville" has been generally applied to these rocks and the underlying Lee Formation. Phalen (1912) had defined the Pottsville and Allegheny Formations in Kentucky as they were generally used in Ohio and Pennsylvania; McFarlan (1943) raised both these units to series rank. The Breathitt Formation is equivalent to the upper part of the Pottsville Formation and all the overlying Allegheny Formation; the top of the Pottsville has not been identified in Kentucky but is thought to occur at about the position of the Princess No. 5 coal bed in northeastern Kentucky.

Series		Formation	North (Princess and Licking River coal reserve districts)	East (Big Sandy coal reserve district)	Southwest (Hazard and Southwestern coal reserve districts)	Southeast (Upper Cumberland River coal reserve district)
UPPER PENNSYLVANIAN	MISSOURIAN AND VIRGILIAN	CONEMAUGH AND MONONGAHELA				
			AMES LIMESTONE MEMBER			
			BRUSH CREEK LIMESTONE MEMBER			
			PRINCESS NO. 10 OR BRUSH CREEK COAL			
			PRINCESS NO. 9 COAL ZONE			
			UPPER FREEPORT COAL			
LOWER AND MIDDLE PENNSYLVANIAN			PRINCESS NO. 8 COAL			
			PRINCESS NO. 7 COAL			
	DES MOINESIAN		PRINCESS NO. 6 COAL			
			HITCHINS CLAY BED			
			VANPORT LIMESTONE AS USED BY PHALEN (1912)			
			PRINCESS NO. 5B COAL			
			KILGORE FLINT; FLINT RIDGE FLINT OF MORSE (1931)		FLINT RIDGE FLINT OF MORSE (1931)	
	?		PRINCESS NO. 5 OR SKYLINE COAL ZONE	RICHARDSON COAL ZONE	KNOB COAL ZONE	
	ATOKAN		TIPTOP COAL	BROAS COAL ZONE	BROAS COAL ZONE	
			PRINCESS NO. 4 COAL		LOST CREEK LIMESTONE OF MORSE (1931)	
			MAIN BLOCK ORE	HINDMAN COAL	HINDMAN OR HAZARD NO. 9 COAL	
			PRINCESS NO. 3, MUDSEAM, OR NICKELL COAL	PEACH ORCHARD COAL ZONE	HAZARD NO. 8 OR FRANCIS COAL ZONE	
				BUFFALO CREEK COAL	HAZARD NO. 7 COAL ZONE; BIG WHEEL COAL	HIGH SPLINT COAL
			HAZARD OR INDEX COAL; PRATER COAL ZONE	HAZARD COAL ZONE; WINIFREDE COAL	HAZARD COAL ZONE; LEATHERWOOD OR BRADEN MTN. COAL	RED SPRINGS COAL
			HADDIX COAL ZONE; TRACE FORK COAL	HADDIX COAL ZONE	HADDIX COAL ZONE; RED ASH COAL	LOW SPLINT OR MORRIS COAL; REYNOLDS SANDSTONE MBR.
	?		MAGOFFIN MEMBER	MAGOFFIN MEMBER	MAGOFFIN MEMBER	MAGOFFIN MEMBER
	MORROWAN	BREATHITT	TAYLOR COAL	TAYLOR COAL	COPLAND OR SHARP COAL	LIMESTONE COAL
			HAMLIN COAL ZONE	HAMLIN COAL ZONE	HAMLIN COAL ZONE; BEACH GROVE COAL	PARDEE COAL; JESSE SANDSTONE MBR.
					HATFIELD COAL	HIGNITE OR SMITH COAL
			FIRE CLAY-WHITESBURG COAL ZONE: FIRE CLAY RIDER COAL	FIRE CLAY RIDER COAL	BIG MARY COAL	STRAY COAL ZONE
			FIRE CLAY COAL	FIRE CLAY OR HAZARD NO. 4 COAL	HAZARD NO. 4, WINDROCK, OR DEAN COAL	WALLINS CREEK COAL
			LITTLE FIRE CLAY COAL	LITTLE FIRE CLAY COAL	UPPER PIONEER COAL	
			WHITESBURG COAL	WHITESBURG COAL ZONE	WHITESBURG COAL ZONE	PUCKETT SANDSTONE MBR.
			KENDRICK SHALE OF JILLSON (1919)	KENDRICK SHALE OF JILLSON (1919)	KENDRICK SHALE OF JILLSON (1919)	KENDRICK SHALE OF JILLSON (1919)
			GUN CREEK OR CANNEL CITY COAL	WILLAMSON COAL	LOWER PIONEER COAL; AMBURGY COAL ZONE	STERLING COAL; CREECH COAL ZONE
				AMBURGY COAL ZONE	JORDAN COAL	POPLAR LICK COAL
				ELKINS FORK SHALE OF MORSE (1931)	ELKINS FORK SHALE OF MORSE (1931)	ELKINS FORK SHALE OF MORSE (1931)
			TOM COOPER, VAN LEAR, OR LITTLE CANEY COAL	UPPER ELKHORN NO. 3, THACKER, OR CEDAR GROVE COAL ZONE; NOSBEN COAL	UPPER ELKHORN NO. 3 COAL ZONE; ELK GAP COAL	TAGGART COAL ZONE; BUCKEYE SPRING OR DARBY COAL
				SIDNEY COAL	LICK FORK COAL	TAGGART MARKER OR KELLIOKA COAL
			GRASSY COAL	UPPER ELKHORN NO. 2 COAL; ALMA COAL ZONE	JELLICO COAL ZONE	MINGO OR HARLAN COAL ZONE; COLLIER COAL
				UPPER ELKHORN NO. 1 COAL		
				CAMPBELL CREEK LIMESTONE OF WHITE (1885)		
			BRUIN OR WOLF CREEK COAL	LOWER ELKHORN OR POND CREEK COAL	VIRES COAL; BLUE GEM COAL ZONE	
			GRAYSON SANDSTONE BED	POWELLTON COAL ZONE	LITTLE BLUE GEM OR BLACK WAX COAL	RICH MTN., PATH FORK, OR IMBODEN COAL
						PHOEBE COAL
			FROZEN SANDSTONE MEMBER		DIXIE COAL	
				CANNELTON LIMESTONE OF WHITE (1885)		
			ZACHARIAH OR WHEELERSBURG COAL	CLINTWOOD OR MATEWAN COAL; BINGHAM COAL ZONE	LILLY, COLONY, MANCHESTER, RIVER GEM, OR SWAMP ANGEL COAL	KENT OR BENNETTS FORK COAL; HANCE COAL ZONE
		LEE AND BREATHITT	VAN CLEVE COAL	CEDAR COAL; GLAMORGAN COAL ZONE	CORBIN SANDSTONE MEMBER	
			CORBIN SANDSTONE MEMBER	EAGLE LIMESTONE OF WHITE (1891)		
			MINE FORK COAL	LITTLE CEDAR OR HAGY COAL	GRAY HAWK COAL	MURRAY, CHANOA, OR MASON COAL
				SPLASH DAM COAL	BEATTYVILLE OR TATTLERS COAL	SPLITSEAM COAL
UPPER MISSISSIPPIAN AND LOWER PENNSYLVANIAN			WARM FORK COAL	ELSWICK COAL	BARREN FORK COAL	REX OR CLEAR FORK COAL
				LOWER BANNER COAL	ROCKCASTLE SANDSTONE MEMBER	YELLOW CREEK SANDSTONE MEMBER
				LEE UNDIVIDED		NAESE AND BEE ROCK SANDSTONE MEMBERS; NAESE COAL
					BEAVER CREEK COAL	TUNNEL OR RAVEN COAL
			ANTHONY COAL		STERNS NO. 1½ COAL	
	CHESTERIAN AND MORROWAN		OLIVE HILL CLAY BED OF CRIDER (1913)		HUDSON, LEE NO. 1, OR STERNS NO. 1 COAL	
		PENNINGTON AND LEE			LIVINGSTON CONGLOMERATE	MIDDLESBORO SANDSTONE MEMBER
						CUMBERLAND GAP COAL
						WHITE ROCKS SANDSTONE MEMBER
						CHADWELL MEMBER
						PINNACLE OVERLOOK MEMBER

FIGURE 13.—Correlation chart of the Pennsylvanian of eastern Kentucky showing coal beds and other key beds. Members of the Lee Formation are shaded. Coal reserve districts from Huddle and others (1963).

bonaceous and contain plant fragments; some thin zones contain brachiopods, pelecypods, cephalopods, gastropods, and crinoids. The subgraywacke is commonly fine grained, and grades into siltstone; it is characteristically micaceous and quartz rich (55 to 70 percent). Ironstone occurs principally as sideritic concretions in thin discontinuous lenses or nodules in siltstone or shale; iron ores in the form of silty to sandy siderite or limonite occur as pods generally less than 50 cm thick at the base of the formation and in the upper part of the section in northeastern Kentucky. Calcareous rocks occur as rare concretionary zones in sandstone and as small to large argillaceous concretions in siltstone and shale; the latter are commonly associated with marine horizons but may not contain fossils.

The Breathitt Formation is not readily divisible into lithologic units. Subdivision of the formation is based on the recognition of key beds, generally coal beds and marine zones and, because single beds do not persist across the entire basin, on sequences of key beds. The Fire Clay coal bed with its distinctive hard flint-clay parting was the first to be recognized as an important key bed, and has been used extensively as a structure horizon. The flint-clay parting, as much as 40 cm thick, is reported to contain sanidine and may be the alteration product of a volcanic ash fall (Seiders, 1965). Other coal beds are locally useful as key beds, particularly commercial coal beds that have wide extent and are exposed by mining operations.

The best stratigraphic tools for the correlation and subdivision of the Breathitt Formation are marine zones several of which are of wide extent. The most important are the Magoffin Member, the Kendrick Shale of Jillson (1919), and the Lost Creek Limestone of Morse (1931). These units resemble one another in their lithologic character and are comparable to the marine parts of Weller's cyclothem (in Wanless and Weller, 1932, p. 1003). They are an upward-coarsening, bay-fill sequence of argillaceous and sandy sediments from 1 to as much as 35 m in thickness that were deposited after rapid marine transgressions over very extensive flat shelves. The lower part of the marine deposits is a dark-gray fossiliferous clay shale that locally contains thin beds or concretions of fossiliferous limestone. These beds grade upward into gray siltstone containing thin discontinuous lenses of siderite. The marine zones commonly overlie a coal bed; the top is marked by an unconformity, generally at the base of a channel-fill sandstone or at the base of a coal bed.

None of the named marine zones extend across the entire coal field, and few have been identified in more than a small part of it. The Magoffin Member has the widest distribution, but it too becomes thin, discontinuous, and ferruginous along what is interpreted to have been the margins of its bay in northeastern Kentucky.

Marine invertebrate fossils are present in many parts of the Breathitt Formation, but they are unusual in any given section. Most occurrences other than in the named marine zones are thin, indistinct and sparsely fossiliferous marine bands in siltstone and shale sequences that have little continuity (Eagar, 1973). These marine bands do not coincide with changes of lithology and are probably related to changes in salinity in small shallow bays or tidal channels. Because many marine zones in eastern Kentucky are not associated with large open bay deposits such as the Magoffin, they must have formed at least 50 km, and perhaps more than 75 km, from such environments.

In the eastern and southeastern parts of the basin, the marine zones in the lower part of the Breathitt below the Magoffin are more numerous, thicker, more continuous, more fossiliferous and contain a larger variety of fossil fauna. This distribution suggests that open marine waters reached eastern Kentucky from the south and southwest along the axis of the subsiding Appalachian geosyncline rather than from the north and northwest as has been suggested by Donaldson (1974) and by Horne and others (1974). Similar conclusions were reached by Nelson (1925) with regard to rocks of the same age in southern Tennessee. Only in strata above the Magoffin did marine transgressions enter the basin from the west and north. The Vanport Limestone as used by Phalen (1912) and younger Pennsylvanian marine zones occur only in northeastern Kentucky and are related to southward- and southeastward-transgressing seas.

Thick (10 to 40 m) sandstone deposits of the Breathitt are generally less massive and resistant than the orthoquartzite of the Lee Formation. They appear to be stacked deposits of shallow anastomosing streams. Channel cuts deeper than 5 m are rarely observed. Grain size varies from sandstone set to set, commonly from bed to bed; only the uppermost channel deposit has in its upper part the fining-upward sequence characteristic of the classic fluviatile deposit. Thick sandstone deposits commonly show rapid lateral lithologic changes and rarely form mappable units, and even the named sandstone members are difficult to recognize short distances from their type areas.

The distribution of sandstone and shale in the Breathitt Formation has not been studied systematically. Analyses of small areas support general impressions that the lower part of the Breathitt is dominantly siltstone and shale, and the upper part mostly sandstone (Huddle and Englund, 1966). In an eight-county area across the central part of the coal field, the line of greater than 50 percent sandstone follows and generally encloses the outcrop of the upper part of the Breathitt as it is preserved along the axis of the broad eastern Kentucky syncline (Newell and Rice, 1977). (See fig. 15.) The sandstone content also apparently increases in the lower part of the formation in the easternmost part of the State. Subangular quartz grit and well-rounded quartz pebbles in coarse-grained sandstone occur locally in two areas along the margins of the State: in the Jesse and Reynolds Sandstone Members in the middle Breathitt in the northeastern part of the Cumberland overthrust block, and in the upper Breathitt in northeastern Kentucky. Current directions in the Breathitt have not been studied, but sediments probably were derived from Appalachian highlands to the east and southeast.

CONEMAUGH AND MONONGAHELA FORMATIONS

The Conemaugh and Monongahela Formations are not separately differentiated in Kentucky because of their lithologic similarity. In other areas of the Appalachian basin, the Conemaugh is defined as extending upwards from the top of the Upper Freeport coal to the base of the Pittsburgh coal. In Kentucky, both these coal horizons occur in poorly exposed shale sequences and are only tentatively identified as thin discontinuous coal or underclay zones. As a result, the base of the Conemaugh is commonly projected from other stratigraphic horizons or is placed at the base of persistent and conspicuous red and variegated shale.

The Conemaugh and Monongahela Formations crop out in an area of about 1,000 km^2 in northeastern Kentucky and have a combined thickness of more than 175 m; the thickness of the Conemaugh is estimated to be about 110 m. They are mainly siltstone and shale and contain various amounts of subgraywacke, limestone, and coal. The siltstone and shale are various shades of red, green, and gray; they are commonly calcareous and many contain thin beds and concretions of marine limestone. Black shale in the upper part of the Conemaugh locally contains conchostracans—brackish- or fresh-water bivalved crustaceans (Connor and Flores, 1978). Subgraywacke occurs locally in channel deposits as much as 30 m thick that are commonly conglomeratic at their base. Marine limestone contain brachiopods, crinoids, gastropods, and fusulinids. Only a few coal beds occur in the lower part of the Conemaugh, and these are thin and discontinuous.

Regional studies suggest that rocks of Conemaugh and Monongahela age were deposited by northwest-flowing streams (Wanless, 1975a, p. 49–53; Arkle, 1974, p. 28). Shallow fresh-water lakes formed locally on the delta plain particularly during Monongahela deposition, and deltaic deposits were repeatedly inundated by eastward-transgressing seas, particularly during Conemaugh time.

Red and green shale, characteristic of the Conemaugh, first occurs in the upper 50 m of the Breathitt Formation, where greenish-gray shale is interbedded with the usual dark-gray shale of the Breathitt, in what is perceived as a "greening" of the shales; reddish-gray shale first appears in the upper 25 m. These changes of color are thought to be related to a reduction in the amount of organic matter in the sediments and may represent a gradual shift toward less extensive swamps in contiguous areas and perhaps toward arid conditions in the source area.

PENNSYLVANIAN STRATA OF WESTERN KENTUCKY

The Pennsylvanian strata of the western Kentucky coal field occupy about 12,000 km^2 of the southeastern part of the Eastern Interior basin, and are about 1,200 m thick. Like the Pennsylvanian rocks in eastern Kentucky, they are largely deltaic in origin and contain many coal beds. However, marine limestone makes up a larger part of the section in western Kentucky than in eastern Kentucky.

GEOLOGIC SETTING

The Pennsylvanian rocks of western Kentucky unconformably overlie strata of Mississippian age. The southwestward paleoslope established in Mississippian time and shown by the sub-Pennsylvanian channel systems (fig. 7) probably was maintained throughout most of Pennsylvanian time (Potter, 1963). The oldest Pennsylvanian strata deposited in these channels are pebbly orthoquartzites, assigned to upper Morrow age by Wanless (1975b, p. 74).

Pennsylvanian strata in the Eastern Interior basin thicken toward a depocenter in southeastern Illinois (McKee and Crosby, 1975, pl. 11). In western Kentucky, the interval between the No. 9 coal bed of Pennsylvanian age and the Vienna Limestone of Mississippian age ranges only from about 370 to 460 m and suggests that subsidence was nearly uniform over the area during Early and Middle Pennsylvanian time. Some eastward thinning of strata in western Kentucky (fig. 10) might suggest the influence of the Cincinnati arch during Pennsylvanian time.

The effect of the Cincinnati arch on Pennsylvanian deposition has long been a matter of speculation (Ashley, 1907; Miller, 1910). Detailed correlations between the Appalachian and Eastern Interior basins have been hampered by the lack of key beds common to both basins and by the great variability of thickness (particularly in eastern Kentucky) and lithology of the Pennsylvanian sediments. Correlations, such as those shown in figure 10, have been based upon sparse paleontological evidence. Regional studies by Potter and Siever (1956a, b) and Siever and Potter (1956) of the petrology, crossbedding directions, and sources of the basal Pennsylvanian sediments in the Eastern Interior basin indicate that the Cincinnati arch was not a major barrier to southwest transport of sediment derived mainly from source areas in the middle and northern Appalachians and the southeastern Canadian Shield.

Fusulinids of Early Permian age from drill core samples in the Bordley quadrangle (R. C. Douglass, written commun., 1977) occur in the uppermost part of the section in a conformable sequence of shale and limestone (fig. 10).

Cretaceous rocks are present to within 24 km of the western margin of the coal field and may have overlapped Pennsylvanian strata; however, they have not been recognized in the coal field. Pleistocene lake beds and outwash cover much of the low-lying areas along stream valleys adjacent to the Ohio River; in the same area, thick deposits of loess blanket hills (Ray, 1965; Shaw, 1915, Frye and others, 1972). These preglacial Pleistocene deposits and locally as much as 60 m thick in the valleys of the Ohio and Tradewater Rivers.

STRATIGRAPHY

The Pennsylvanian strata of western Kentucky are divided into four formations, in ascending order, the Caseyville, Tradewater, Carbondale, and Sturgis Formations (fig. 14). Formations above the Caseyville are not lithostratigraphic units, and their boundaries are commonly placed at regionally persistent coal beds. The Caseyville Formation, like the Lee Formation of eastern Kentucky, is character-

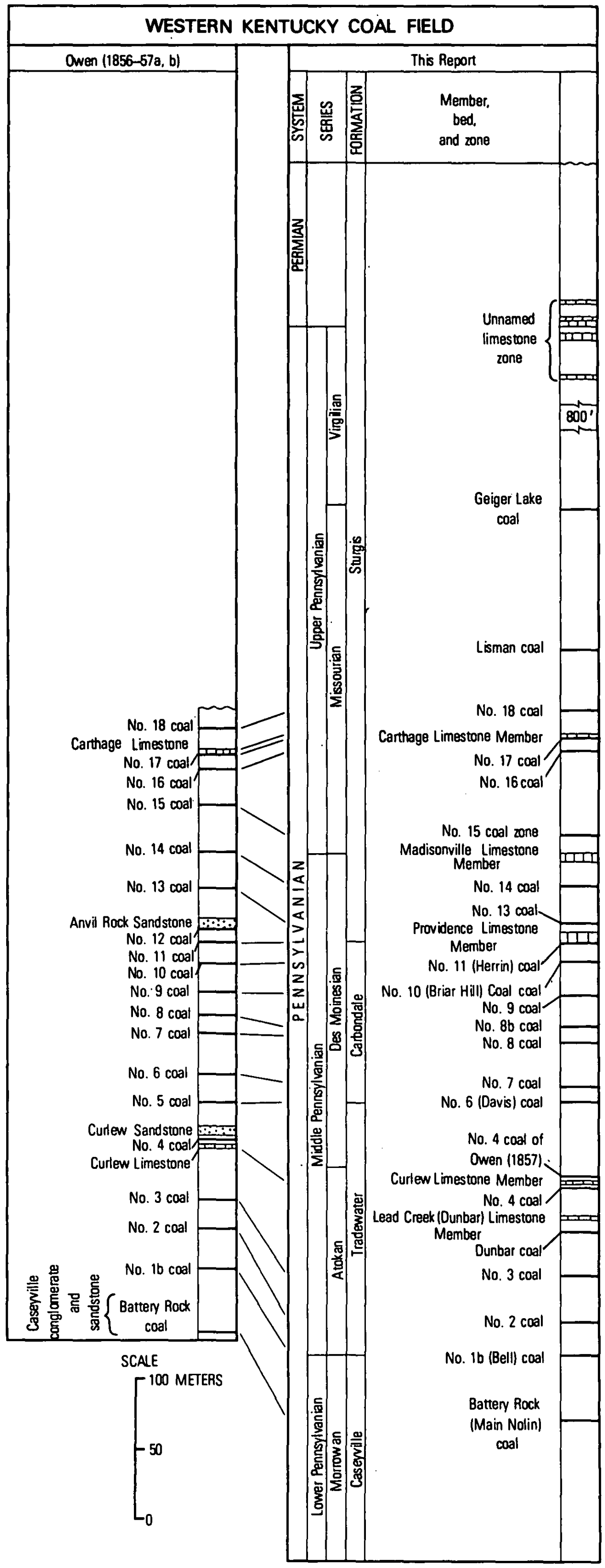

FIGURE 14.—Diagram comparing nomenclature of Owen (1856, 1857a, b) with that of this report.

ized by pebbly orthoquartzite; some of the basal sandstone is more than 75 m thick. However, the Caseyville, locally more than 200 m thick, is in places dominantly shale and siltstone. The top of the formation is arbitrarily placed at the base of the No. 1b (Bell) coal bed where present, or is placed at the top of a persistent sandstone; in many places the Caseyville cannot be differentiated from the overlying Tradewater Formation. Subgraywacke is dominant above the Caseyville, although Siever (1957) reported a transitional zone between orthoquartzite and subgraywacke in the lower part of the Tradewater Formation. Because of poor exposure, much of the stratigraphy of the Pennsylvanian of western Kentucky is known primarily from subsurface data.

The Pennsylvanian rocks consist of carbonaceous siltstone and clay shale, generally medium- to fine-grained sandstone, marine limestone containing brachiopods, pelecypods, cephalopods, gastropods, crinoids, bryozoans, corals, and fusulinids in beds from less than 2 to more than 9 m thick; and argillaceous and concretionary nonfossiliferous limestone. Sandstone and siltstone constitute about 55 to 80 percent of the Pennsylvanian section, and silty shale and clay shale, generally associated with coal and limestone beds, make up about 20 to 45 percent.

Limestone beds, although they make up only about 5 percent of the section, are an important tool for coal exploration and stratigraphic analysis. More than 35 marine transgressions have been recorded in the Pennsylvanian section of the Eastern Interior basin (Wanless, 1975b, p. 72). In western Kentucky, four limestone horizons are recognized as being regionally persistent: the Curlew Limestone Member of the Tradewater Formation, and the Providence, Madisonville, and Carthage Limestone Members of the Sturgis Formation. The Lead Creek or Dunbar Limestone Member of the Tradewater Formation is found only in the eastern part of the coal field.

About 24 principal coal beds or coal zones have been identified in western Kentucky. Most of these are shown in figure 14. The most persistent and thickest coal beds occur in the upper Tradewater Formation, the Carbondale Formation, and the lower Sturgis Formation. These include the Dunbar and Nos. 4, 6, 7, 9, 11, 12, 13, and 14 coal beds.

The No. 11 coal bed contains a distinctive clay shale parting that can be traced throughout the Eastern Interior basin, making the coal bed the most useful marker in the western Kentucky coal field. This parting, 5 to 10 cm thick, generally is light bluish gray, and is referred to as the "blue band." It has a pelletal or grainy structure similar to some flint clays but is composed of illite, chlorite, and kaolinite (Woltman, 1956).

The Pennsylvanian rocks of western Kentucky and the Eastern Interior basin were deposited in alternately deltaic and shallow marine environments resulting in repeated sequences of strata that have been attributed to diastrophic changes (Weller, 1956) or to eustatic sea level and climatic changes (Wanless and Shepard, 1936). These deposits probably resulted from a normal depositional pattern in a slowly subsiding basin that had a continuous source of terrigenous sediments (Wanless and others, 1970). Interpretations of Pennsylvanian deposition in the Eastern Interior basin indicate that it was dominated by many prograding and shifting delta lobes of the Michigan River system (Pryor and Sable, 1974).

BIOSTRATIGRAPHY OF THE PENNSYLVANIAN OF KENTUCKY

Pennsylvanian System boundaries are all poorly defined in Kentucky, and their position as shown in the column (figs. 13 and 14) should be considered approximate. Most Pennsylvanian flora and fauna in Kentucky consist of relatively long-ranging forms of little value for detailed stratigraphic work. Most have not been systematically studied. The earliest investigations of fossil flora in Kentucky by Lesquereux (1857, 1861) were in part summarized by Nőe (1923). Read and Mamay (1964) divided the Upper Paleozoic into 15 floral zones and assigned 9 of these, zones 4 through 12, to the Pennsylvanian. All the Pennsylvanian zones occur in eastern Kentucky. They have also assigned the strata in western Kentucky to floral zones 6 through 12; however, they reported that plant fossils transitional to zones 4 and 5 occur in basal Pennsylvanian strata in Indiana. None of the zonal boundaries of Read and Mamay correspond to lithostratigraphic horizons in Kentucky.

Kosanke (1965a, b, 1966, 1967, 1968, 1969, 1971, 1972) studied the spore assemblages of eastern Kentucky Pennsylvanian coals, but he indicated that the range zones of only a few taxa are useful for even the most general regional and interregional correlations. In detailed studies of coals in part of northeastern Kentucky, Kosanke (1973) suggested that the Princess 5B coal bed occurs at about the same stratigraphic position as the Davis or No. 6 coal bed of western Kentucky. (See fig. 10). He also correlated the Princess No. 7 coal bed with the Briar Hill or No. 10 coal bed of western Kentucky. These analyses refer only to the youngest coals in the Pennsylvanian section of eastern Kentucky; regional and interregional coal correlations for most of the Breathitt and Lee Formations still depend mainly upon interpretations of physical stratigraphy.

Coal-ball material has been described by Schopf (1961) from the Hamlin coal zone in eastern Kentucky and has been reported from the No. 11 coal of western Kentucky from a locality about 3.5 km northwest of Providence. (See fig. 15.) The latter contains a lycopsid-dominated assemblage that includes stems of the following genera: *Lepidocarpon, Cordaite, Sphenophyllum, Sigillaria,* and *Medullosa* (J. M. Schopf, 1963, written commun.).

Pennsylvanian fauna of Kentucky have not been studied in detail. Morse (1931) cataloged and listed most of the major Pennsylvanian marine horizons in eastern Kentucky. Furnish and Knapp (1966) and Strimple and Knapp (1966) studied ammonoids and crinoids of upper Morrowan age from the Kendrick Shale of Jillson (1919) in detail, but only limited studies of megafauna (Cox, 1857) and microfauna (Thompson and Shaver, 1964) of western Kentucky have been published.

Wanless (1975a and b) made extensive use of fusulinid zones for regional and interregional correlations of the Pennsylvanian of the Appalachian and Eastern Interior basins. These fossils locally are abundant in many of the marine limestones of western Kentucky but have not been carefully studied. A fusulinid that has "intermediate" attributes between *Profusulinella* and *Fusulinella* has been identified in the Lost Creek Limestone of Morse (1931) in southeastern Kentucky (Ping, 1978); no specific equivalent has been found in western Kentucky, but taxonomically it falls between the forms in the Lead Creek Limestone and the Curlew Limestone Members of the Tradewater Formation (R. C. Douglass, 1978, written commun.). Wanless (1975b, p. 81) indirectly correlated the Curlew Limestone of the Tradewater Formation of western Kentucky with the Magoffin Member of the Breathitt Formation of eastern Kentucky on the basis of occurrences of *Fusulinella iowensis* in the Curlew and in Mercer Limestone Members of the Pottsville Formation in Ohio. However, the Magoffin apparently occurs well below the *Fusulinella* zone and therefore below the Curlew Limestone. Limestone equivalent to the Mercer of Ohio has not yet been identified in Kentucky, but fusulinids do occur in the Vanport Limestone as used by Phalen (1912) and in the Brush Creek Limestone and Ames Limestone Members of the Conemaugh Formation in northeastern Kentucky. The Brush Creek contains *Triticites ohioensis*; a related species, *Kansanella* sp. aff. *K. Tennis*, is reported from the Carthage Limestone Member of the Sturgis Formation of western Kentucky (R. C. Douglass, 1978, written commun.).

POST-CARBONIFEROUS TECTONIC EVENTS

After deposition of the Pennsylvanian rocks, the southeastern part of the Appalachian basin was warped upward to form the broad eastern Kentucky syncline (fig. 15); this event was probably associated with a northwestward movement of about 12 km of the Cumberland overthrust block.

Two major fault systems, the Irvine-Paint Creek and the Kentucky River fault systems, cross the northern part of the Cumberland Plateau and extend into central Kentucky. They show a maximum vertical displacement of Pennsylvanian rocks of about 75 m; the down-dropped block is to the south.

The Moorman syncline in western Kentucky appears to have been a subsidiary depocenter of the Eastern Interior basin in Pennsylvanian time. In late Paleozoic or early Mesozoic time, movement in the Rough Creek and Pennyrile fault systems resulted in further downwarping of the syncline and in making it a distinct structural basin.

The Rough Creek fault system is about 5 to 8 km wide and extends westward from central Kentucky through the central part of the western Kentucky coal field. It consists of many normal and thrust(?) faults which form a series of grabens and horsts. Vertical displacement along the system is as great as 900 m.

The Kentucky River, Irvine-Paint Creek, and Rough Creek fault systems are part of the 38th parallel lineament, a west-trending alinement of structural features extending from northeastern Virginia to south-central Missouri. Post-Pennsylvanian movement appears to have been mainly vertical, although en echelon faulting of short (8 km), northeast-oriented, normal faults occurs north and south of the Rough Creek system and may represent strike-slip movement. Regional Bouguer gravity anomaly patterns in eastern and central Kentucky suggest a right-lateral offset of about 80 km in the Precambrian basement (Heyl, 1972). Peridotite intrusions and fluorite mineralization in western Kentucky and kimberlite dikes in northeastern Kentucky may be related to this deep-seated zone of weakness. Radiogenic age dating of biotite from peridotite and

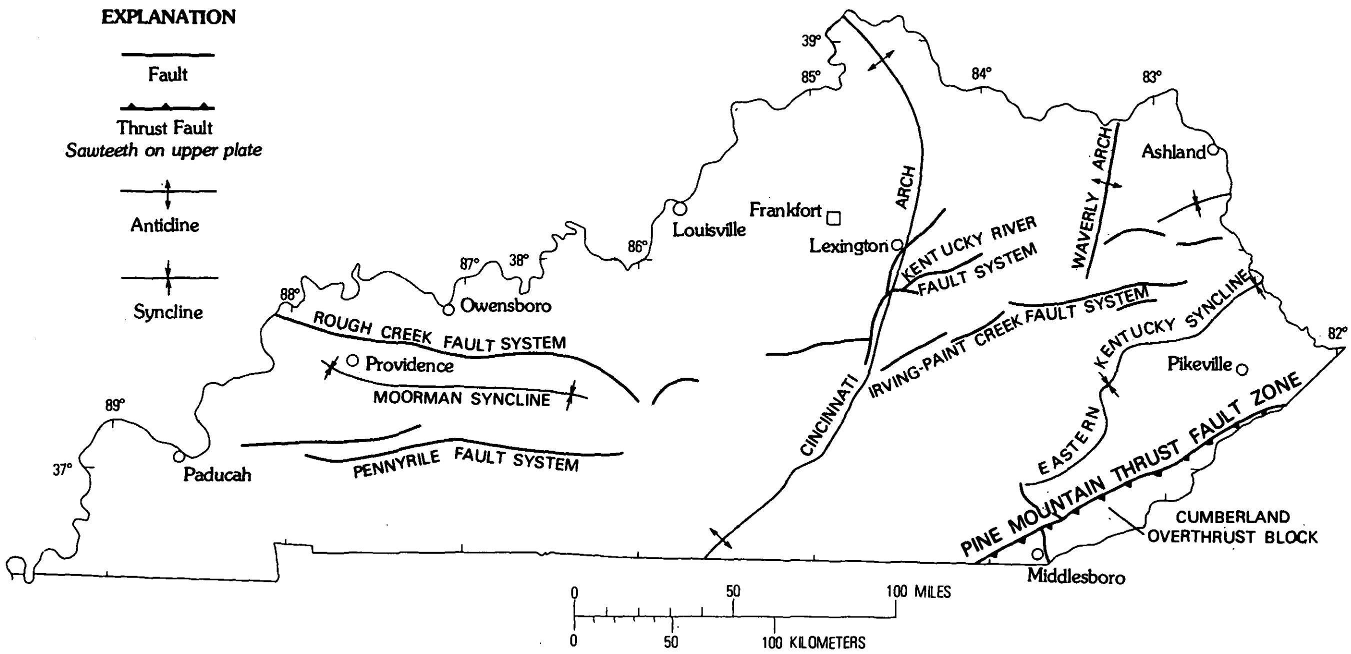

FIGURE 15.—Generalized structure map of Kentucky.

kimberlite intrusions indicates emplacement in Early Permian time (Zartman and others, 1967).

The City of Middlesboro is in a crater-like structure about 5.5 km in diameter in which the Pennsylvanian rocks are intensely deformed and locally brecciated. Englund and Roen (1962) noted shatter cones in sandstones in the center of the basin and interpreted the feature to be a meteorite-impact crater.

ECONOMIC GEOLOGY

Coal is the principal mineral resource of the Carboniferous in Kentucky. Beds of Pennsylvanian age have yielded more than 4.06×10^9 metric tons since commercial production began in about 1790 (Currens and Smith, 1977). Figure 16 shows the distribution of production between the eastern and western coal fields and the important contribution of surface mining in the last three decades. Much of eastern Kentucky production has come from coal beds in the Elkhorn coal zone; most western Kentucky production has come from the Nos. 9 and 11 coal beds.

The coal is high-volatile A and B bituminous; the eastern Kentucky coal is of higher rank and generally lower in ash and sulfur content than the western Kentucky coal. Most coal is produced for utility or steam coal, but many coals of eastern Kentucky are used in the production of high-quality metallurgical coke. Estimates of original reserves in beds thicker than 35 cm for eastern Kentucky are 30.33×10^9 metric tons and for western Kentucky, 35.27×10^9 metric tons (Huddle and others, 1963).

Carboniferous strata are also a major source of oil, natural gas, and industrial and metallic minerals in Kentucky (figs. 17 and 18). An estimated 60 to 80 percent of the State's oil production and an estimated 50 to 70 percent of its natural gas production have come from Carboniferous rocks. Kentucky's cumulative production of oil from 1883, the first year in which production records were kept (Crawford, 1958), through 1976 is 86.4×10^6 metric tons. Cumulative natural-gas production is estimated to be 92.6×10^9 m^3. Mississippian units in western Kentucky have been the principal source of Carboniferous oil, and Mississippian rocks in eastern Kentucky have been the principal source of Carboniferous natural gas. Of the 1×10^6 metric tons of oil produced in Kentucky in 1976, about 70 percent came from Mississippian sandstone and limestone and about 5 percent came from Pennsylvanian sandstone. Of the 1.8×10^9 m^3 of natural gas produced during 1976, about 55 percent was from Mississippian sandstone and limestone and about 5 percent from Pennsylvanian sandstone.

Mississippian limestone is the principal source of crushed stone for construction and agricultural use in western, south-central, and eastern Kentucky; most of the quarries and underground mines producing stone from Mississippian rocks operate

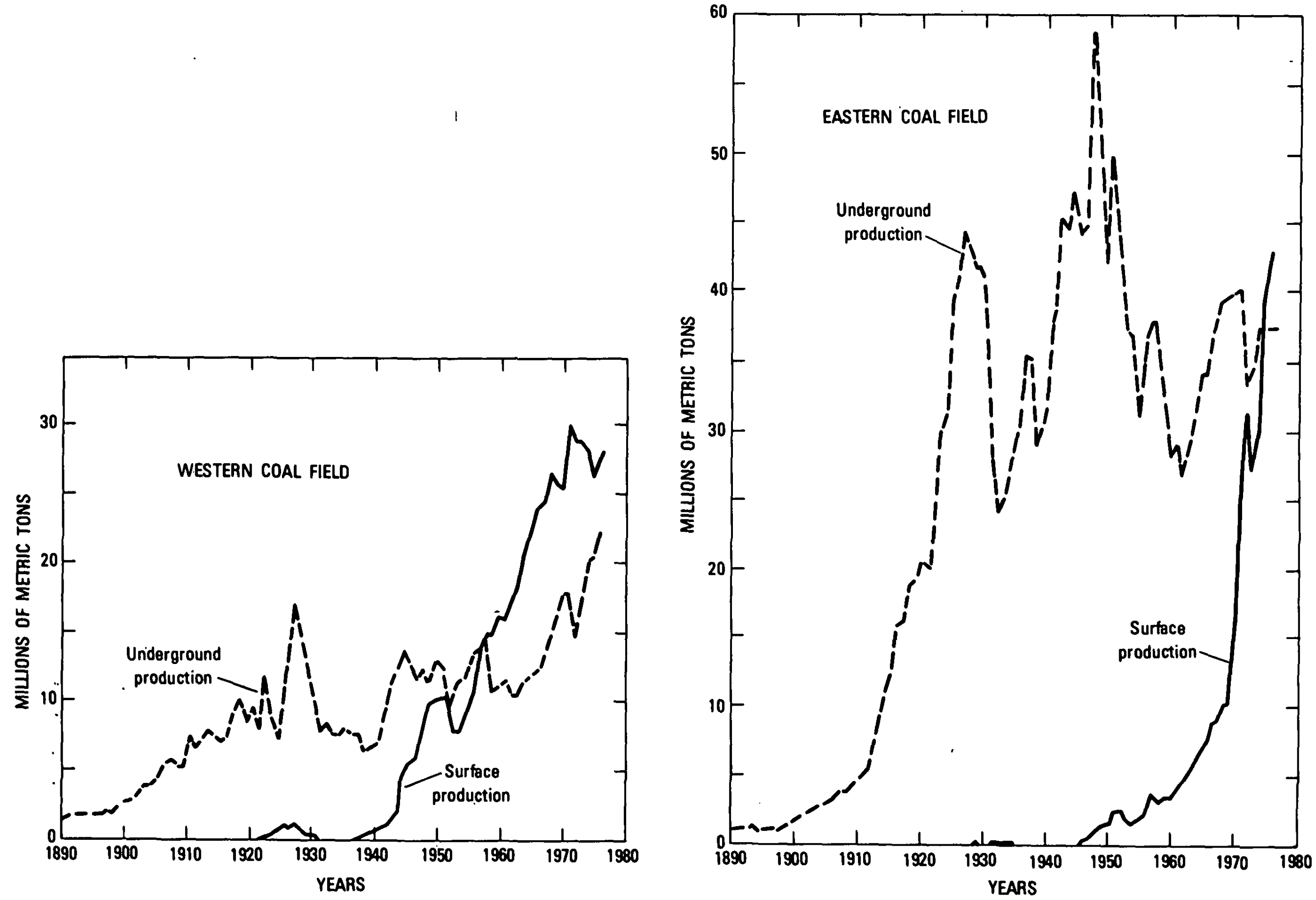

FIGURE 16.—Coal production of the eastern and western coal fields of Kentucky from 1890 to 1975 showing surface and underground mining. Auger production included in surface production. Surface production not significant and not separately reported prior to 1920. Modified from Currens and Smith (1977).

partly or entirely in the Ste. Genevieve Limestone. Small quantities of limestone have also been obtained from thin beds of Pennsylvanian age. High-calcium limestones, mainly oolitic limestones of the Ste. Genevieve Limestone, Girkin Formation, and Newman Limestone (Mississippian), are used for cement, fluxstone, rock dust for underground coal mines, and formerly for lime. Oolitic limestones of the Girkin and, to a lesser extent, the Ste. Genevieve have been quarried for building stone in south-central Kentucky. Pennsylvanian sandstone is crushed for construction aggregate. Road-surfacing material has been produced from rock asphalt deposits in sandstone of the Caseyville Formation (Pennsylvanian) and Big Clifty Sandstone Member of the Golconda Formation (Mississippian) in west-central Kentucky. Deposits of high-silica sandstone of both Mississippian and Pennsylvanian ages have been sources of glass, molding, and foundry sands, sandstone of the Caseyville is being used in the manufacture of ferrosilicon. Dimenson stone has been produced from Mississippian siltstone and sandstone and Pennsylvanian sandstone.

Mississippian shale and Pennsylvanian shale and underclay are used for the production of structural clay products, mainly brick and tile, and, at one site, for lightweight aggregate. In northeastern Kentucky, a major fire-brick industry was based on deposits of refractory clay in the Breathitt Formation (Pennsylvanian), the main source being the Olive Hill Clay Bed of Crider (1913) in the basal part of the Breathitt.

Fluorspar has been mined from deposits in Mississippian rocks of the western Kentucky fluorspar district, about 25 km northeast of Paducah. Sphalerite (locally the principal mine product), galena, barite, cadmium, germanium, and silver have been recovered as byproducts of fluorspar mining. The ore bodies occur as vein deposits along faults and, to a lesser extent, as bedding-replacement deposits (Trace, 1974).

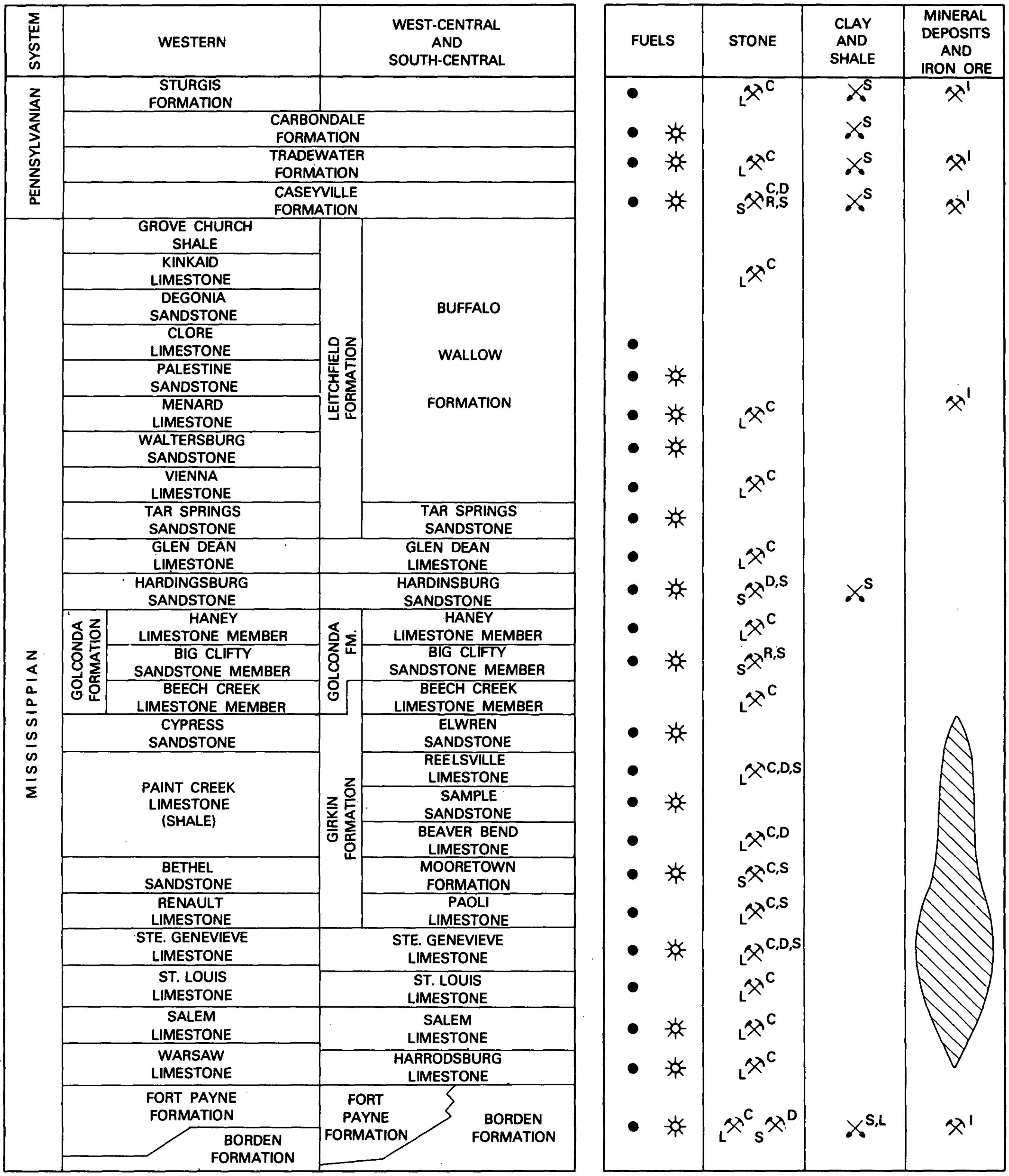

FIGURE 17.—Sources of oil, natural gas, and industrial and metallic minerals in Carboniferous rocks of western Kentucky. Stratigraphic range of principal mineral deposits from Amos (1974) and Trace (1974). For explanation see figure 18.

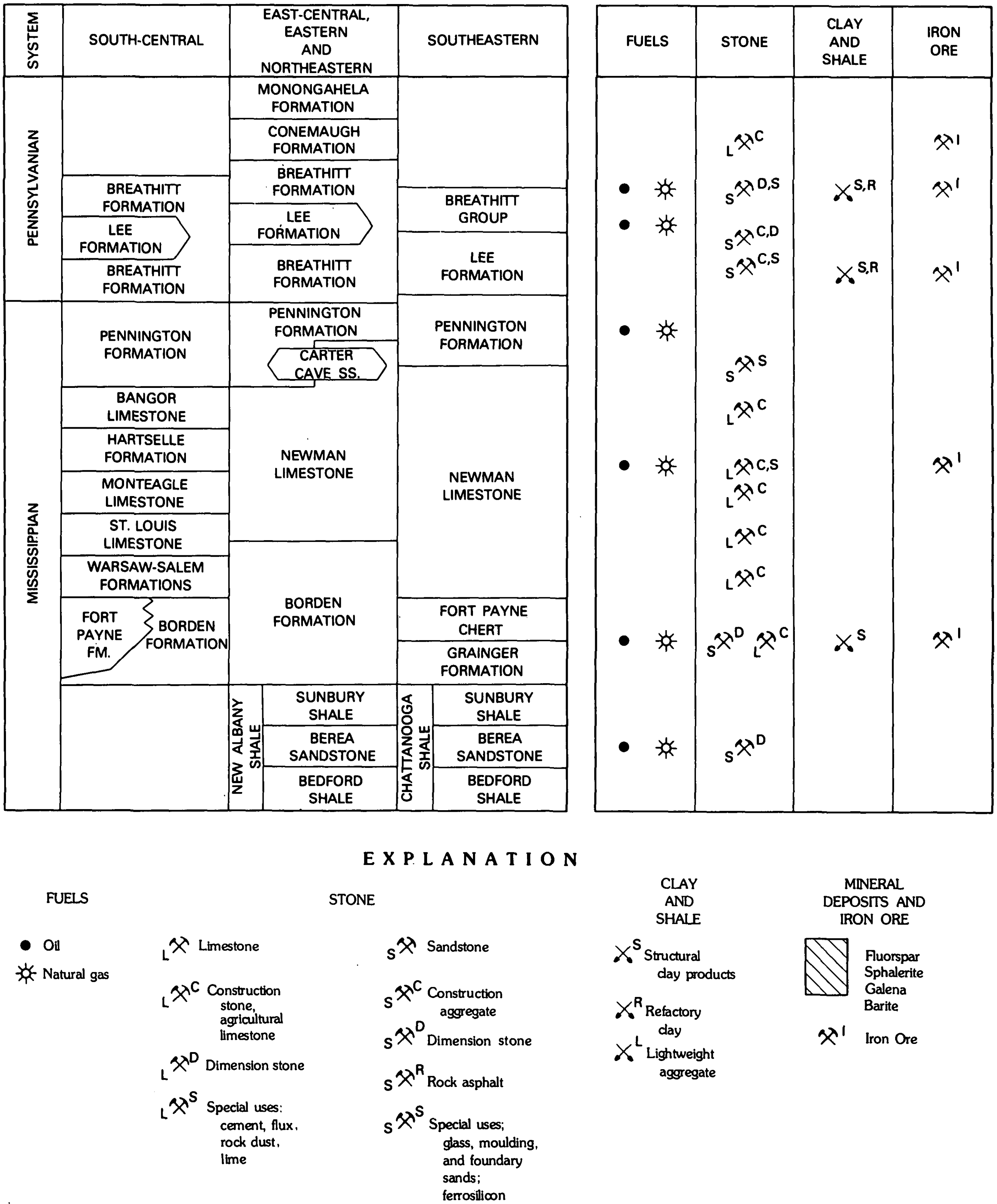

FIGURE 18.—Sources of oil, natural gas, and industrial and metallic minerals in Carboniferous rocks of eastern Kentucky.

Limonitic and sideritic iron ores in Carboniferous rocks were mined extensively during the 19th century for smelting in local furnaces. Deposits in the Breathitt and Conemaugh Formations (Pennsylvanian) and at the top of the Newman Limestone (Mississippian) were sources of ore for furnaces in northeastern and east-central Kentucky. Furnaces were built at several locations in west-central and western Kentucky to utilize ore from deposits in Mississippian and Pennsylvanian units.

Subsurface deposits of gypsum and anhydrite in the lower St. Louis Limestone (Mississippian) of west-central Kentucky may be a potential resource (McGrain and Helton, 1964).

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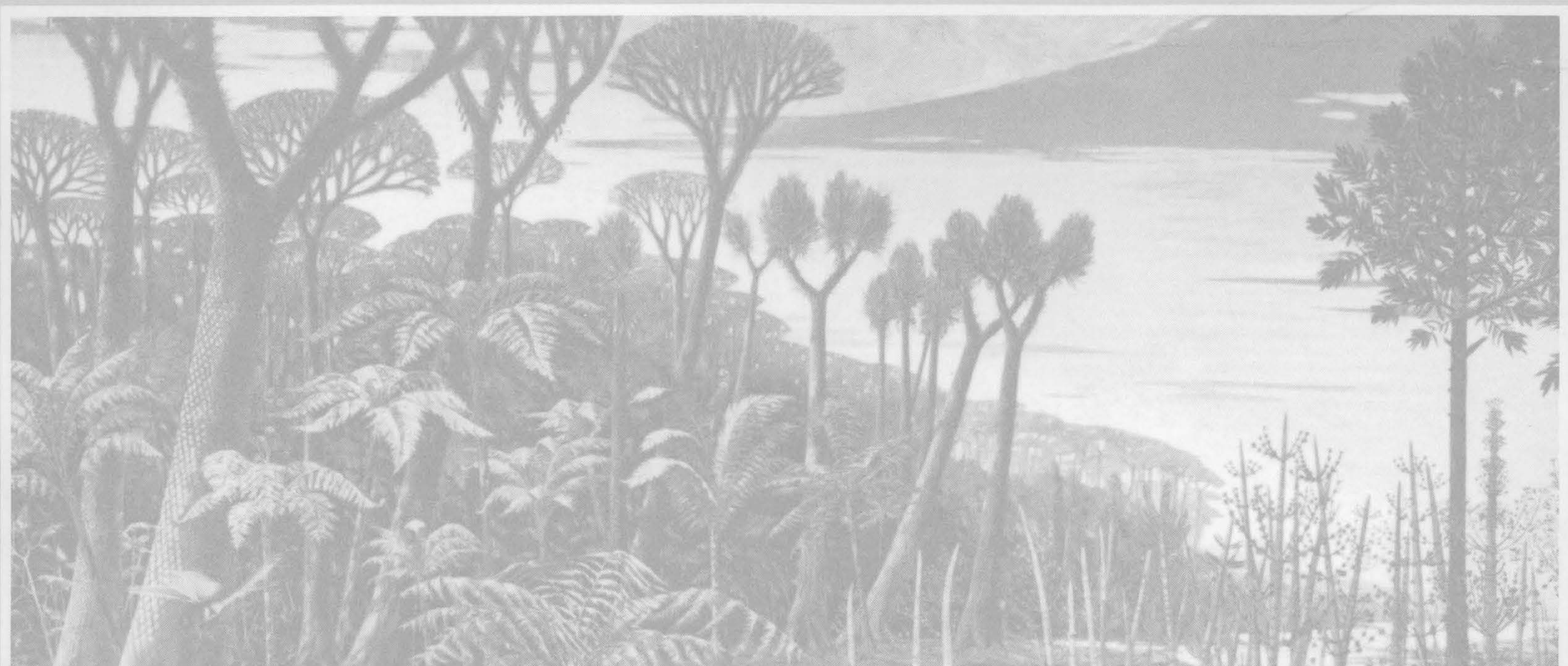
The Mississippian and Pennsylvanian (Carboniferous) Systems in the United States



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ON THE COVER

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

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

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

C. Virginia, by Kenneth J. Englund

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

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

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

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

I. Alabama and Mississippi
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H. William Menard, *Director*

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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.

FOREWORD

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

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

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

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